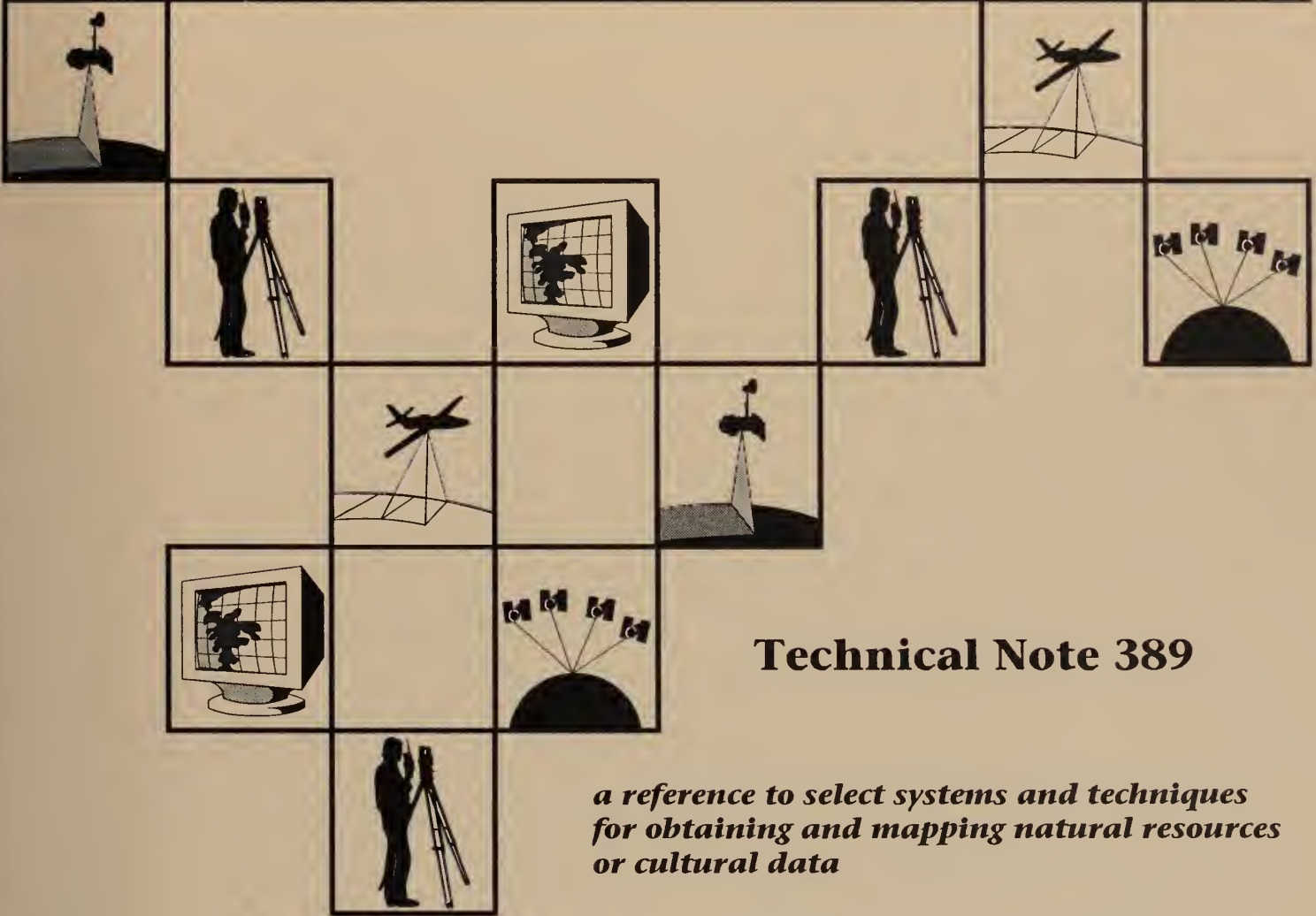




The Geo-Positioning Selection Guide for Resource Management



Technical Note 389

a reference to select systems and techniques for obtaining and mapping natural resources or cultural data

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The Geo-Positioning Selection Guide for Resource Management

Technical Note 389

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September 1993

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Preface

The term “*geo-position*” is an abbreviation of geographic position, which refers to the geographic coordinates, or latitude and longitude, of natural resource or cultural features on or near the earth’s surface. The *Geo-Positioning Selection Guide for Resource Management* started as a professional paper in 1988 for the first International Symposium on Advanced Technology in Natural Resource Management. It was published in the *Resource Technology 88* proceedings as *GIS Resource Data and GPS* by John B. Keating, Jr. Since the initial publication of that paper, geo-positional technology has improved and acquisition costs have decreased; subsequently, the need for information about obtaining geographic coordinates on resource or cultural phenomena has greatly expanded.

This guide is a general reference that provides a limited amount of information about major or unique geo-positioning technologies. It is intended to help resource managers and specialists learn more

about the tools available for mapping geographic coordinates for Geographic Information Systems (GIS); however, potential users of these technologies should check with their agencies’ technical experts for additional information on specific capabilities of existing systems. Eventually, this guide will become part of a more complex handbook which will provide more technical mapping and geo-positioning reference materials to GIS and mapping science professionals and technicians.

There are two parts to this guide. This first part consists of general narrative describing the many different systems and their relationships to each other. The second part is a fold-out wall chart that has the geo-positioning technologies organized by their accuracy levels and cross-referenced to their discipline by color. The chart can be used with the guide or on its own as a reference for making daily decisions in minerals, renewable resources, and operations field activities.

Acknowledgements

Several Bureau of Land Management (BLM) personnel assisted in the production of this guide, including Mike Hutt, formerly the Chief, Photogrammetry Section, Service Center, and now with the Branch of Photogrammetry, Rocky Mountain Mapping Center, U.S. Geological Survey; Dave Meier, Lead Cartographer, Washington Office; and Fred Batson, Chief, Branch of Mapping Sciences, Jim Turner, Chief, Remote Sensing Section, and their technical staffs at the Service Center. Gretchen Meyer, Natural Resource Specialist, Wyoming State Office; Don Gray, Lead Cartographer, Utah State Office; and John Lee,

Chief, Branch of Cadastral Survey, and members of the Cadastral Survey staff in the Wyoming State Office assisted in the review of the draft document. Many other individuals, too numerous to mention, contributed their time and efforts in a variety of ways. John Moeller, Deputy Assistant Director, Support Services, Washington Office, has supported the development of this guide and greatly assisted in identifying resources to publish it. The Technology Transfer Staff at the Service Center, including Linda Hill, Beth Roetzer, and Peter Doran, edited and produced the final document.

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Executive Summary

The Geo-Positioning Selection Guide for Resource Management is designed to assist Bureau of Land Management (BLM) resource specialists and managers in selecting the most economical and beneficial system for collecting field data and mapping geographic coordinates of both natural resource and cultural data.

BLM field offices collect natural resource data daily. The multidisciplinary nature of BLM's work requires a whole suite of geo-positioning technologies. For example, there may be specific requirements for activities such as mapping soils or vegetation, obtaining Universal Transverse Mercator (UTM) coordinates of an archeology site for the National Historic Register, locating coal drill holes to determine the amount of coal under a proposed lease, or performing digital analysis of oil and gas well positions on million dollar drainage cases. Each activity may require a different geo-positioning technology to meet its specific requirements.

Geo-positioning information directly supports BLM's multiple-use mission, as all relevant data have to be mapped spatially prior to analysis and evaluation for land management decisions. Such information is also valuable for BLM's Automated Land and Mineral Record System (ALMRS), which is spatially based and requires geographic coordinates for most data. Additionally, there has been an increase in the use of automated Geographic

Information Systems (GIS) data analysis for land management activities. GIS requires geographic coordinates as well. This increase has resulted in a strong demand by other land management agencies, universities, and professional organizations for information on geo-positioning technologies.

The rapid increase in use of GIS in all resource activities prompts the need for better tools and techniques to collect, map, and integrate spatial data. In addition to the traditional technologies available, there are many modern tools and techniques which can be implemented to digitally capture spatial resource data in both the field and the office. In order to help resource managers make an informed decision on which technology to use, this guide describes five categories of tools and techniques available to collect and map these data. Costs, accuracies, and suggested ways to attach spatial coordinates to natural resource and cultural data are reviewed as well. The five geo-positional categories covered are:

1. Terrestrial Positioning Systems
2. Cartographic Reference Systems
3. Aerial Photography, Orthophotography, and Photogrammetric Based Systems
4. Satellite Remote Sensing Systems
5. Satellite Positioning Systems

Introduction

The Bureau of Land Management (BLM) has been collecting and mapping natural resource and cultural data for many years. Some of the mapping tools and techniques in use today have been used for most of this century:

| | |
|----------------------------------|------------|
| map reference | 100+ years |
| field mapping from aerial photos | 75+ years |
| photogrammetry | 55+ years |
| orthophotos | 30+ years |
| inertial systems | 30+ years |
| navigational satellites | 30+ years |
| satellite remote sensing | 25+ years |
| satellite biotelemetry | 22+ years |

Inventorying and mapping resource data can involve intensive field labor. For example, tracking and mapping movements of bighorn sheep can take months, as can intensive mapping of an archeology site. However, traditional mapping technologies are changing, and the use of Geographic Information Systems (GIS) in collecting and mapping resource data is rapidly growing. New GIS applications require most natural resource management data to have geographic coordinates. Geographic coordinates are the common ingredient in diverse resource information systems that allow data to be displayed in map form in their correct spatial relationship to each other.

Current technologies are being honed and improved to provide new tools and techniques for locating and mapping field phenomena. These resource mapping tools can digitally capture spatial resource data, and are becoming more affordable and more readily available to resource specialists. BLM resource specialists and managers are faced with selecting the most economical and beneficial system to meet their specific needs. Because some of these geo-positioning tools are used in highly specialized disciplines, knowledge of their use has been very limited. However, increased use of GIS has created new demand for hands-on use of tools and technologies for all resource specialists and land managers instead of just a few technology experts.

This document is designed to assist resource specialists and managers in selecting spatial coordinate determination and mapping tools and techniques used in the “positional sciences” for resource based GIS. These tools and techniques are used by natural resource specialists and support personnel in their daily field and office activities. The technical aspects of geo-positioning systems involve many professional disciplines in land management, including mapping sciences, civil engineering, cadastral and geodetic surveying, and aircraft flight navigation. When a technique or method is selected, a mapping science specialist, surveyor, or geodesist should be consulted for assistance in the proper application of the technology.

A GIS Versus a Data Base Management System

Location coordinate data allows a GIS to analyze spatial information. Alpha-numeric Data Base Management Systems (DBMS) can store coordinates of data, but can't spatially process, map, or use these coordinates. Spatial data adds an important dimension to a GIS—it allows data to be integrated by storing it in a common structure, and allows spatially related information to be displayed graphically

with great versatility using computer technology. The data can be combined, compared, and analyzed without conversion or transformation of the coordinates. Geographic coordinates further assist resource users in multiple-use analysis, such as when comparing the location of eagle nests with a proposed coal strip mine location, for example.

Coordinate Derivation and Datums for Resource Data

In the past, resource managers either took a map to the field or made a sketch map of the resource feature and its location. Some maps had a standard coordinate system as part of the base. However, many pre-1960 maps, including many produced by natural resource and land management agencies, did not portray a worldwide or absolute coordinate system and only depicted relative locations without a geographic coordinate tie.

The term absolute coordinate system is used here to describe spherical and plane coordinates that can be used on a worldwide basis or converted to a worldwide coordinate system. Both systems have value in the location and spatial analysis of all resource data. All coordinate systems are based on a geodetic description of the shape and size of the earth. An ellipsoid is used to describe the best geometric fit for a portion of the world. As satellite measurements and computational capabilities have improved, geodesists and cartographers have refined the mathematical description of the Earth or a portion of the Earth.

More recent resource base maps have worldwide/absolute coordinate systems including geographic coordinates (latitude and longitude) and two plane coordinate systems, i.e., Universal Transverse Mercator (UTM) and State Plane Coordinate System (SPCS). These two plane coordinate systems can be converted into a worldwide geographic coordinate system, but they are used on a more localized County or State basis for project work. All the tools and techniques described in this guide can be used to obtain all three coordinate types.

Geographic coordinates are based on an ellipsoid and are normally recorded as latitude and longitude in degrees, minutes, and seconds. Plane coordinates

are based on a plane cartesian coordinate system tied to geographic coordinates. UTM is favored for most GIS data bases. The UTM coordinate system divides the Earth's surface into 60 north-south zones with a 6° width (Figure 1). The northing measurement is made in meters from the Equator (0° latitude). The easting measurement is made from the central meridian of each zone. These longitudinal zones are assigned a false origin of 500,000 meters

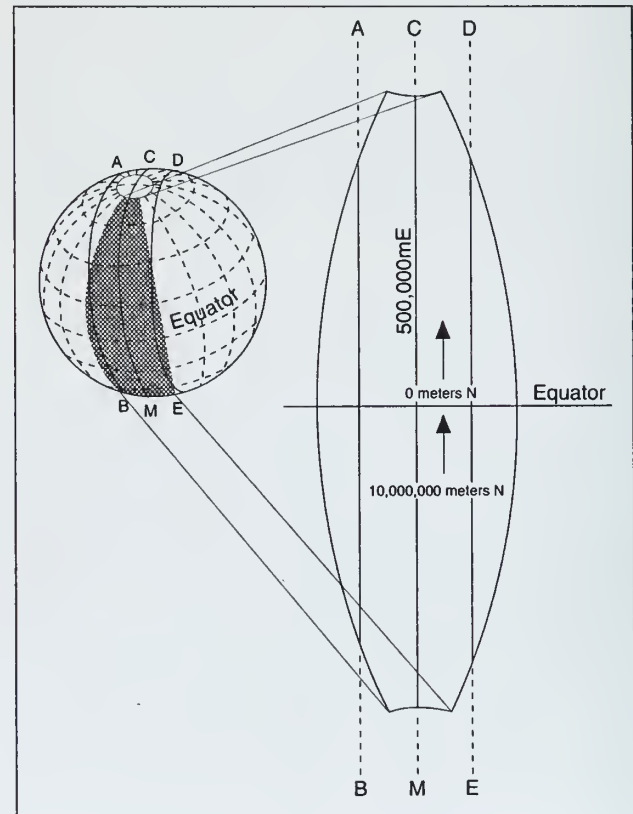


Figure 1. Diagram of one UTM 6° wide (longitude) zone projected from 0° to $84^\circ 30'$ north and 0° to $80^\circ 30'$ south of the Equator.

in the easting direction. These zones are treated as though they were flat or a plane with the Earth's surface projected onto them. The map projection of the plane coordinate system or any map product used to locate or digitize data is recorded on most base maps.

The State Plane Coordinate System (SPCS) is a local plane coordinate system for each state (Figure 2). Some users call it an absolute system because it uses latitude and longitude as its frame of reference. This system was designed as an engineering plane coordinate system for each state to help plan and construct highways, other public works, and local



Figure 2. State Plane Coordinate System (SPCS) zones in the United States.

cadastral surveys. State plane coordinates originated in the 1930's, and most were implemented in the 1940's as states enacted legislation. SPCS became popular with interstate highway system designers. It is also used for large engineering projects such as coal strip mines and large subdivision designs. BLM uses SPCS in coal mining production verification, drill hole coordinate data bases, and some engineering projects that require Federal, State, and County coordination.

Geographic coordinates are based on a reference datum which includes the size and shape of the Earth and the coordinate ties to geodetic survey monuments on the ground. [All geo-positioning technologies are based on the national framework (datum) of geodetic control measurements and monuments throughout the United States. This surveyed reference framework is the responsibility of the National Geodetic Survey, U.S. Coast and Geodetic Survey. All mapping systems are linked to and use this geodetic control network, especially new sys-

tems such as Global Positioning Systems (GPS).] Though there are approximately 100 datums available throughout the world, only three are used for natural resource work in the United States.

A datum refinement and change is taking place in North America. The National Geodetic Survey (NGS) recently implemented the new horizontal North America Datum of 1983 (NAD 83) which will replace the North America Datum of 1927 (NAD 27). This can cause confusion to scientists or resource specialists who want to locate data for spatial analysis in a GIS. All coordinate users should check the datum being used to avoid mixing coordinates with different datums. Coordinates can vary up to 100 meters in the lower 48 States to over 200 meters in areas of Alaska between NAD 83 and NAD 27. Most U.S. mapping products use NAD 27 as the base datum, but GPS normally uses NAD 83 or the military World Geodetic System 1984 (WGS 84). The WGS 84 datum is designed for worldwide geographic coordinate use. GPS is based on WGS 84. It is very similar to NAD 83 and can be treated the same for most resource work in the United States. Coordinates should be converted to a common datum. Historic data or information with a long lifespan should have the base datum recorded, especially for precise locations. The North American Vertical Datum of 1929 (NAVD 29) is used for elevation reference and is tied to the mean sea level. NAVD 29 is currently being revised to NAVD 88.

Most natural resource and land management applications will have to use NAD 27 until all base maps show NAD 83. This process could take 5 to 10 years. Figure 3 shows how the new datums are depicted on U.S. Geological Survey (USGS) maps.

There is a move to improve the SPCS by changing to the NAD 83 datum and identifying the system as the State Plane Coordinate System 1983 (SPCS 83). The National Geodetic Survey has transformed the national geodetic control network to NAD 83 SPCS coordinates. To avoid confusing the user with SPCS coordinates based on NAD 27, the new NAD 83 control monument SPCS coordinates are reported in meters. Care must be taken to identify the system used and the datum on which it is based. This system has been accepted by most State governments as a new standard. The confusion caused by datums, projections, and coordinate systems can be eased by setting a standard for a State or District.

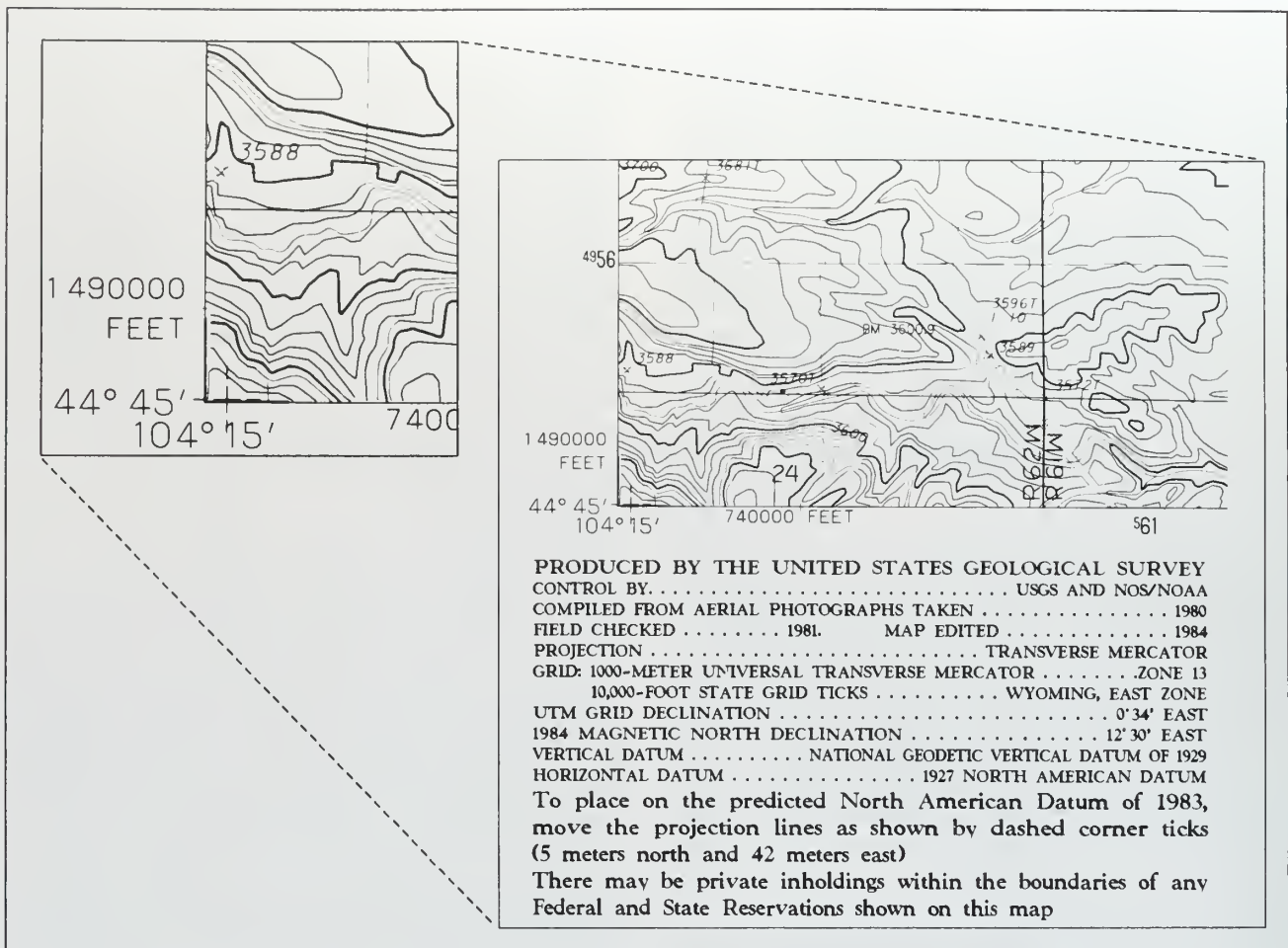


Figure 3. The southwest corner of a USGS topographic map depicting the change from NAD 27 to NAD 83. The small tick mark near the corner of the map shows the predicted NAD 83 7.5-minute map corner.

Positioning Systems Interrelationship

Geo-positioning systems are very interdependent, and each type of system may be based on other positioning technologies. For example, digital geometric positional corrections for Landsat Thematic Mapper (TM) satellite imagery use control from topographic maps. These maps are produced from photogrammetric surveys that have ground control surveys tied to geodetic and cadastral surveys. Modern cadastral surveys are tied to geodetic sur-

veys for geographic coordinates. Each system is based on, and dependent on, other positional technology. This interrelationship can strengthen mapping accuracies by correlating various tools to identify mapping errors; however, it can also cause systematic error in derived mapping products. Even more modern systems, such as GPS, normally use dependent techniques requiring geodetic control to record higher accuracy geographic coordinates.

Coordinate Positional Tools for Natural Resources

This guide divides positional technology into five categories. These categories include a mixture of tools, both manual and fully automated. There can be overlap in the categories and more than one tool in a class can be used at a time. The five categories are:

1. Terrestrial Positioning Systems
2. Cartographic Reference Systems
3. Aerial Photography, Orthophotography, and Photogrammetric Based Systems
4. Satellite Remote Sensing Systems
5. Satellite Positioning Systems

Terrestrial Positioning Systems



Traditional Cadastral and Geodetic Surveys

System Description

Ground surveys, mostly cadastral land description and boundary surveys, have been performed in the United States for over 250 years. The equipment has evolved from magnetic compasses, solar transits, and survey chains to computer-based total stations and theodolites which measure horizontal and vertical angles in seconds and distance in centimeters and provide output to a field data recorder or computer (Figure 4). New surveying equipment includes laser technology to measure distances and angles. Even with new technology, ground surveying still requires intensive field work and technical expertise. BLM is the only Federal agency legally tasked to approve Federal cadastral surveys. NGS, USGS, and other agencies perform control surveys for the national control network and the production of maps.

Traditional ground survey techniques were used to establish the location of geodetic survey control



Figure 4. A BLM cadastral surveyor checks the location of an oil and gas well with a total station survey instrument.

monuments for the national datum frame of reference for the entire United States. These monuments can be used to determine geographic coordinates through survey ties to unknown locations. Survey monuments and their measurements are used as the base reference datum for all natural resource mapping science and geo-positioning activities.

Main Uses

Cadastral surveys create legal land descriptions. Recent cadastral surveys are tied to geodetic control. Control surveys form the national geodetic network base to which most other surveys requiring coordinates are tied. Control surveys are used for mapping and photogrammetric control as well as for engineering location and design and construction surveys.

Resource Mapping Potential

Traditional ground surveys can measure local accuracies in centimeters within the survey area, but absolute accuracies may range up to meters because of the many variables involved. Recently surveys have been used to detect the potential for earthquakes by measuring very minor earth movements across fault lines, with accuracies less than a centimeter in both horizontal and vertical directions. Documented field survey monuments ("brass caps") can provide for the location of resource data. Brass caps can be used for general locations and accurate survey instruments can be used to obtain precise measurements to these monuments.

In most cases precise ground surveys are labor intensive and costly for locating resources. Only very valuable or legal location needs, such as locating a producing oil and gas well in a potential trespass situation, justify the cost of a ground survey. Further information may be obtained from the Manual of Survey Instructions, 1973 (BLM, 1973) and various engineering survey publications. Other mapping tools can be used to help identify a trespass or comparison of legal locations, but only an official cadastral survey should be relied upon for legal location determination, especially for court cases.

Calculated Coordinates From Ties to Surveys

Public Land Survey System Coordinate Adjustment Systems

System Description

BLM has developed unique survey adjustment software using geodetic control coordinates tied to the Public Land Survey System (PLSS). The software calculates the geographic coordinates of all surveyed corners, tied corners, and standard subdivision aliquot parts and was used to develop the PLSS/Geographic Coordinate Data Base (GCDB). Control for this adjustment procedure can come from GPS, TRANSIT satellite, ground geodetic ties, or digitized map or photogrammetry derived coordinates. The initial software used by BLM, the PLSS Coordinate Computational System (PCCS), was the only coordinate computational software for Federal cadastral surveys for over 10 years. New micro-computer-based adjustment software, GCDB Measurement Management (GMM), is undergoing final testing and initial release. GMM software provides for survey data entry, analysis, and adjustment of abstracted data with points of known position, and generates geographic coordinates for all corners. Currently PCCS runs on Prime minicomputers and GMM can use both the Primes and microcomputers. Both software sets are in the public domain and give the user an accuracy report in the form of unresolved errors in the survey data.

Cadastral coordinate computations are dependent upon the era of the most recent survey data and the availability and quality of known coordinates on one or more of the PLSS township corners.

| Year of Survey | Accuracy (meters) |
|-----------------|-------------------|
| 1973 to present | 5 - 30 |
| 1910 to 1973 | 10 - 50 |
| pre-1910 | 30 - 100* |

* Some pre-1910 surveys with high error rates have yielded unresolved errors in excess of 500 meters.

Estimated positional accuracy is available for every computed corner of the PLSS. The known control coordinates can be derived from any one of

several geo-positioning techniques including map digitizing, ground survey ties, or using survey quality differential GPS.

GPS, Doppler, or conventional geodetic traverse geographic coordinates of the four township corners are preferred for the highest quality coordinates. The resultant output of these systems can be uploaded to the Bureau's GCDB with additional survey attribute data. These coordinates do not replace traditional surveys, but give the resource manager greater flexibility to analyze ownership status data and portray the survey digitally in a GIS.

Main Uses

The PCCS or GMM derived coordinates for survey corners are used to produce the landnet cadastre layer for BLM's land management systems. These coordinates, when transferred to BLM's GIS, can be used to portray land and mineral ownership and assist in automated Master Title Plat (MTP) drafting, lease evaluations, and most land management decisions.

Resource Mapping Potential

The resource mapping potential in PCCS or GMM lies in their secondary use to describe ownership digitally by coordinates. Much of BLM's record resource data can currently only be located by section subdivision (aliquot part) on a plat. Almost all land management decisions involve land ownership status by location. Some other data types, such as oil and gas well location coordinates, can be calculated from GCDB data due to their survey tie to BLM's PLSS. Coordinates of survey corner monuments will assist in navigating to corners in the field with technologies such as GPS.

Coordinate Geometry

System Description

Many commercial coordinate geometry (COGO) software packages that run on minicomputers, workstations, or microcomputer systems can compute coordinates from known geodetic control. BLM's GIS uses two such packages for parcel generation and calculation of oil and gas well drill holes.

The BLM's developmental software for graphic parcel generation uses an existing PLSS landnet with corner coordinates to compute simple and complex parcels from a legal description. The parcel coordinates can be projected from existing data bases such as BLM's Automated Land and Mineral Record System (ALMRS), or from keyboard entry of legal parcel descriptions. A graphic map with the new parcels can be plotted on the existing township survey. Parcel locations can then be used for analysis with coal data to estimate the volume of coal under a potential lease parcel. Automated section subdivision software cannot be used in all cases because of unique or very complex surveys.

The geographic coordinates of oil and gas wells can be calculated from their survey ties to existing section lines with a BLM developmental program called Geographic Well Locator (GGWL). The well location dimensions are given in feet, offset from a section line. Coordinates of the section corners in the GIS must first be obtained and then well UTM coordinates calculated using the survey offsets in order to compute the derived well coordinates (Figure 5).

Main Uses

COGOs in BLM are primarily used to generate coordinates from distance and bearing surveys with ties to geodetic control, usually a section corner with geographic coordinates. They are mainly used to locate oil and gas wells, but can be used to map raptor nest/siting locations along with other point data that has been tied to a section corner with surveyed offsets.

Resource Mapping Potential

COGOs have limited use in BLM, but can be used to calculate point or linear surveyed feature coordinates such as roads, fence lines, etc. A potential example would be a road centerline survey with a survey tie to a known geographic coordinate point, such as a geodetic control monument or a PLSS corner with a GCDB coordinate. The COGO software can calculate and derive a geographic coordinate for all turn points on the road survey. The road location coordinates can then be imported into a GIS data base. High potential for error exists because this technique uses two independent local measurement

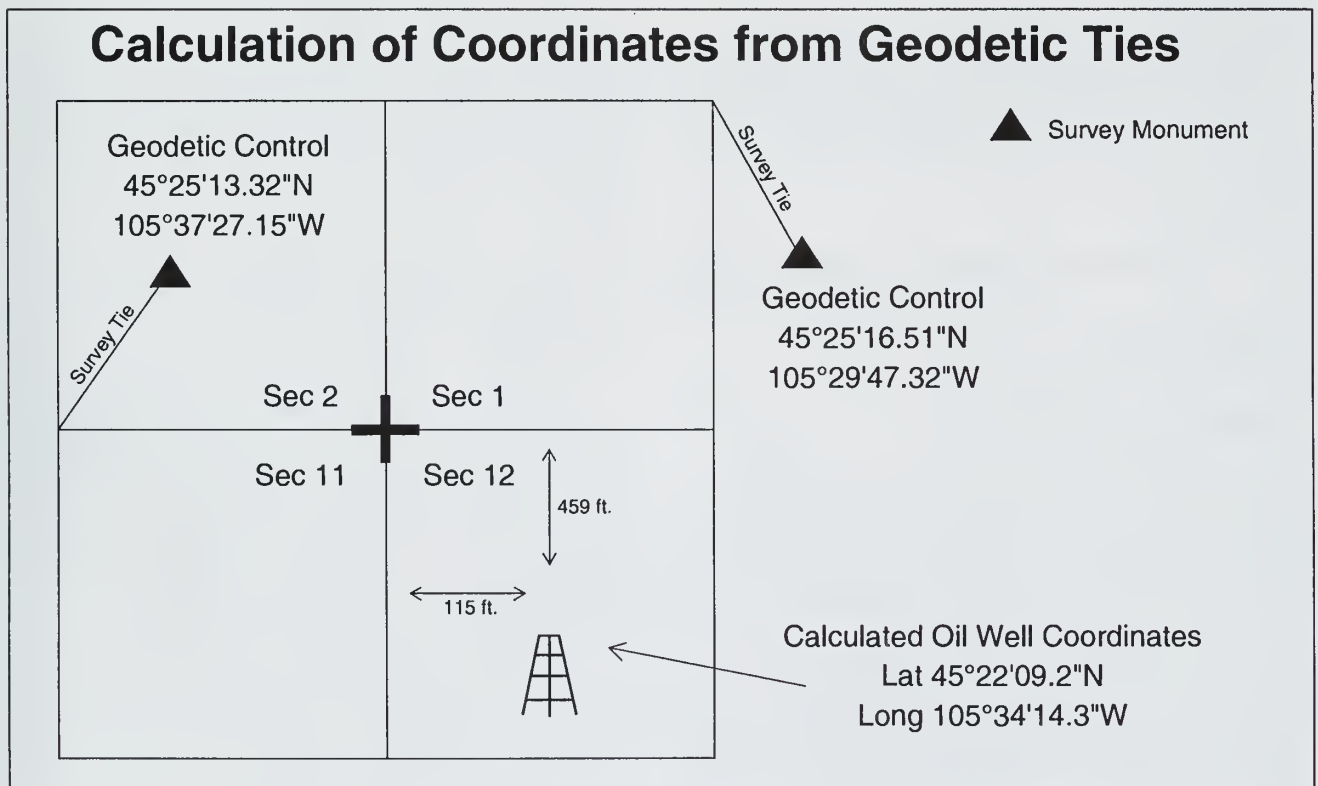


Figure 5. With COGO, an oil and gas well's coordinates can be calculated using the legal description and ties to the PLSS.

systems to calculate absolute coordinates. Errors have exceeded 1,000 feet (312 meters) when locating coordinates for oil and gas wells and raptor nest sites. Extensive quality control and error sampling should be used with this technique.

Inertial Survey Systems

System Description

Inertial Survey Systems (ISSs) are based on high-precision gyroscopes that measure the rate of instantaneous change through the use of accelerometers after initialization with control coordinates. As an accuracy check, ISSs should return to a known coordinate monument after survey completion. They have one distinct advantage over most systems as they give a continuous, real-time record of ISS unit positions. Until the recent use of satellite point positioning systems, ISS offered the only fully-automated, field coordinate location system (Hatfield, 1978). The on-board ISS computer can be used to find a location by coordinates. However, ISSs are expensive—the first ground systems cost over \$250,000.

Main Uses

The primary uses of ISS are in aircraft and ship navigation. When all parameters are followed, the submeter accuracies obtained make the units excel-

lent for control survey extension by ground vehicle and helicopter. BLM has been using two inertial systems in Alaska as the primary measuring devices on cadastral surveys and identify protracted coordinates in the field. They have been used for location of seismic surveys, photogrammetric control for engineering scale mapping, densification surveys, control for analytical aerotriangulation, mine engineering control, rights-of-way, and other linear surveys. The vertical measurement accuracies are approximately half the horizontal accuracies (USFS, 1985).

Resource Mapping Potential

Although expensive and costly to operate in the field, inertial instruments are cost effective in locating offshore oil rigs, vessels, buoys, and geophysical and oceanographic data. They are most cost effective for resource work in dynamic situations where good positional coordinates are required. Inertial systems are best used for linear or near linear corridors. Vehicle mounting limits the system to sites accessible by vehicle. Use in a helicopter limits the accuracy of the ISS and requires special costly flight procedures (USFS, 1985). Inertial systems are being replaced or supplemented by GPS technology in most field applications. Recent tests by BLM's Alaska State Office and in Canada have demonstrated increased potential for hybrid ISS that have been combined with GPS in remote survey applications.

Active and Passive Transmitters and Receivers

LORAN C

System Description

LORAN C radio navigation is an air and sea navigation system in which simultaneous signals from a master station and at least two slave stations are received and interpreted as differences in distance from the stations. These systems give the location in LORAN C coordinates that must be converted into the geographic coordinates of the user system. In the past few years, LORAN C has added transmitters in the midcontinent area to improve navigation in the central United States. It is expected that the more accurate GPS will replace or supplement LORAN C in the next few years. LORAN C is a passive system that only requires a receiver in the air/seacraft.

Main Uses

LORAN C is primarily used for offshore navigation by both ships and aircraft. There are geographic limitations caused by distance from the LORAN C transmitters. Terrain can mask the signal, especially in mountainous areas or near ground level.

Resource Mapping Potential

LORAN C has been used to map wildfire locations by aircraft in Alaska and locate and map side scan sonar ocean and lake bottom data for GIS analysis (Brown et al., 1988). BLM uses aircraft units in helicopters to find dropoff and pickup points for field survey crews. Aircraft units also have proven cost effective in preprogramming flights to find several field sites spread over 100 miles in

western Wyoming. LORAN C is also useful in aerial wildlife surveys and mapping animal distribution if the more accurate GPS capabilities are unavailable. The units are moderately priced and accuracies in the range of 100 to 250 meters can be obtained under ideal conditions. GPS is quickly replacing LORAN C for most resource mapping applications.

Automated Lightning Detection System

System Description

The Automated Lightning Detection System (ALDS), implemented by BLM in the Western United States as part of its fire management program, uses ground stations to detect ground lightning strikes. This system was developed from 1970 Canadian technology to include the detection and mapping location of 99 percent of ground lightning strikes to an accuracy of approximately 1 minute of latitude and longitude [± 1 mile (1.6 km)]. ALDS uses Direction Finders (DF) to detect the unique

magnetic and electrical signals produced by all ground strike lightning flashes (Maier et al., 1983). The signal is uploaded to and transmitted by satellite communications to a positional analysis station in Boise, Idaho. ALDS measures angular accuracies of $\pm 1^\circ$ for lightning occurring within 100 nautical miles of a DF. The location of the strike is then transmitted via satellite to computer screens with map graphics in 11 Western States, as in Figure 6 (German, 1987).

Main Uses

ALDS is used for the detection and immediate mapping of lightning-caused wildfires.

Resource Mapping Potential

Resource mapping potential is limited to the identification of potential fire locations due to ground lightning strikes. Use of ALDS can reduce the number of field aircraft inspections and flights during the fire season. The system is also used to monitor the intensity and history of thunderstorms.

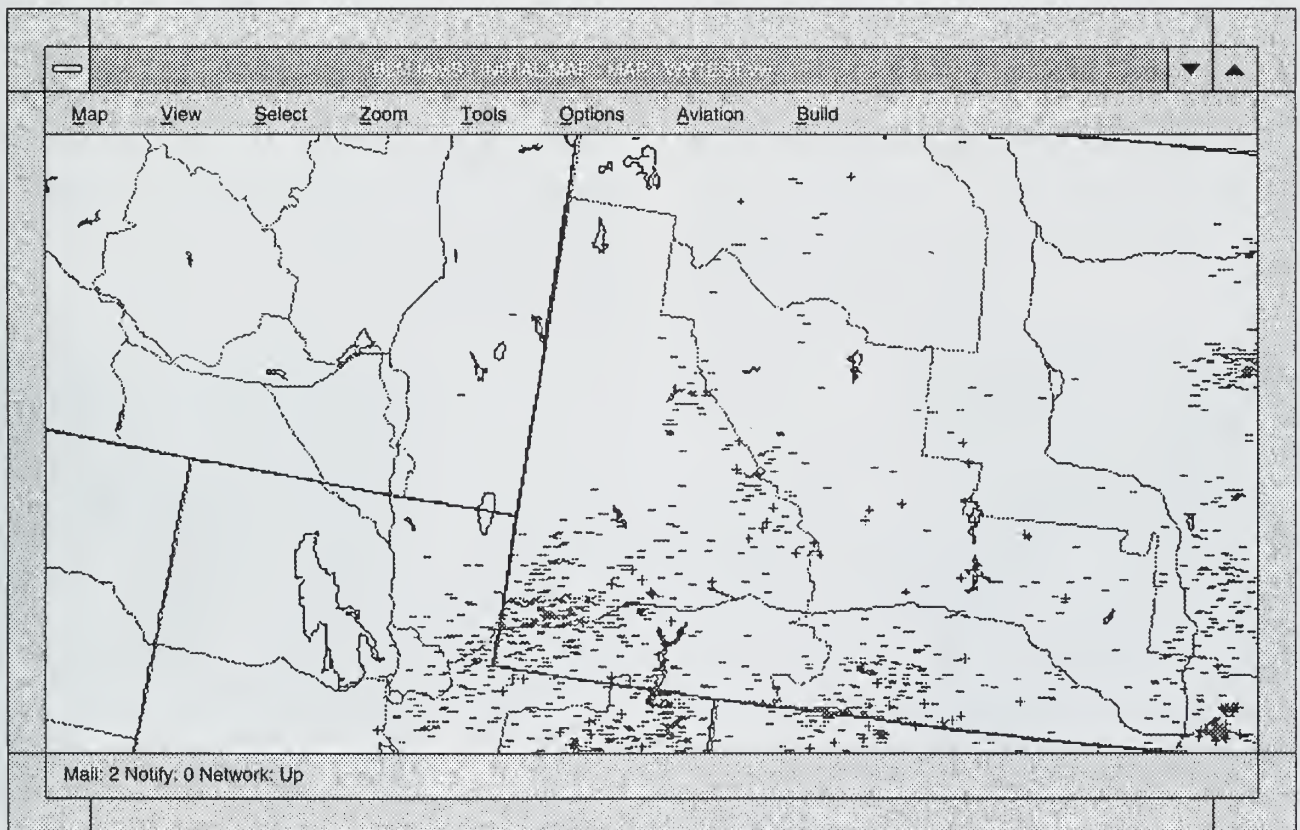


Figure 6. Computer map of southwest Wyoming from BLM's Initial Attack Management System (IAMS). The map shows lightning strike locations for a 3-day period in August 1993 for the Automated Lightning Detection System (ALDS). ALDS is an early detection system for potential wildfires.

Radiotelemetry Wildlife Tracking System

System Description

Radiotelemetry was first used during World War II to triangulate the location of enemy radio transmitters. Radiotelemetry is an active system requiring a radio transmitter on the subject to be tracked and an antenna and receiver at the tracker's location. Since the late 1960's, transmitters in the 164 MHz range have been attached to smaller and smaller game animals to track and plot their locations on maps (Judd and Knight, 1977). Tracking has been done using both aircraft and handheld ground antennas (Craighead, 1969). Accuracies have been reported to 0.65 km by plotting locations on 1:62,500 maps (Craighead, 1970). Obtaining coor-

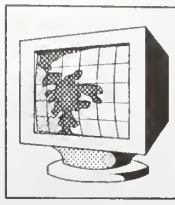
dinates is very labor intensive from the ground and loses accuracy from aircraft. This system only provides the user with local bearing to the transmitter, which can be plotted and triangulated on a map to obtain a geographic coordinate.

Main Uses

Radiotelemetry is used for local tracking of wildlife and wild horses that have a radio transmitter attached to a collar.

Resource Mapping Potential

Radiotelemetry's resource potential is very limited due to the need to place a small transmitter on the subject to be tracked, but its use has provided valuable data on the migration of game herds and large mammals.



Cartographic Reference Systems

Resource Mapping Using Topographic Maps and Orthophotos

System Description

Topographic (topo) maps and orthophotoquads are the workhorses of resource spatial data location and data entry into GIS. Orthophotoquads are aerial photography with all radial, terrain, and lens distortions removed so they are orthogonal (correct shape) and meet the definition of a map. Orthophotoquads have evolved into an excellent mapping tool. (For more information on orthophotos, see the Aerial Photography, Orthophotography, and Photogrammetric Based Systems section.) Resource data can be directly mapped onto topographic maps or orthophotoquads. Data can also be collected on aerial photos in the field and then transferred onto maps or orthophoto overlays. The data are digitized directly from the map overlays using the map spatial coordinates as control.

Main Uses

Cartographic tools provide the resource specialist with the ability to accurately (spatially) orient resource data to the rest of the world. Topo maps and orthophotoquads are used for soil, vegetation, archeological, hydrographic, transportation, and other inventories, especially those requiring inter-

pretation and plotting to maps (Figure 7). Resource features that follow or coincide with mapped features are easy to transfer to a map. Topo maps and orthophotos can be used for point, line, and polygon data locations. They work well with aerial photography-based inventories where the photo inventory data are transferred to a map.

Resource Mapping Potential

Over the last 10 years, use of topographic maps and orthophotoquads as the mapping base for resource data has increased. Many users require current photography to collect data, which is then transferred to orthophoto overlays. The data overlays are then manually or scan digitized. This is one of the least expensive techniques to obtain resource data coordinates. Accuracies are directly related to base map scale, type of data to be mapped, and to the user's ability to plot the resource data on the map.

For most natural resource data, accuracies on USGS 7.5-minute, 1:24,000 scale topographic maps will be no better than the National Map Accuracy Standards (NMAS), ± 12.5 meters (40 ft) for 90 percent of the well defined points, and errors can range up to ± 50 meters (160 ft).

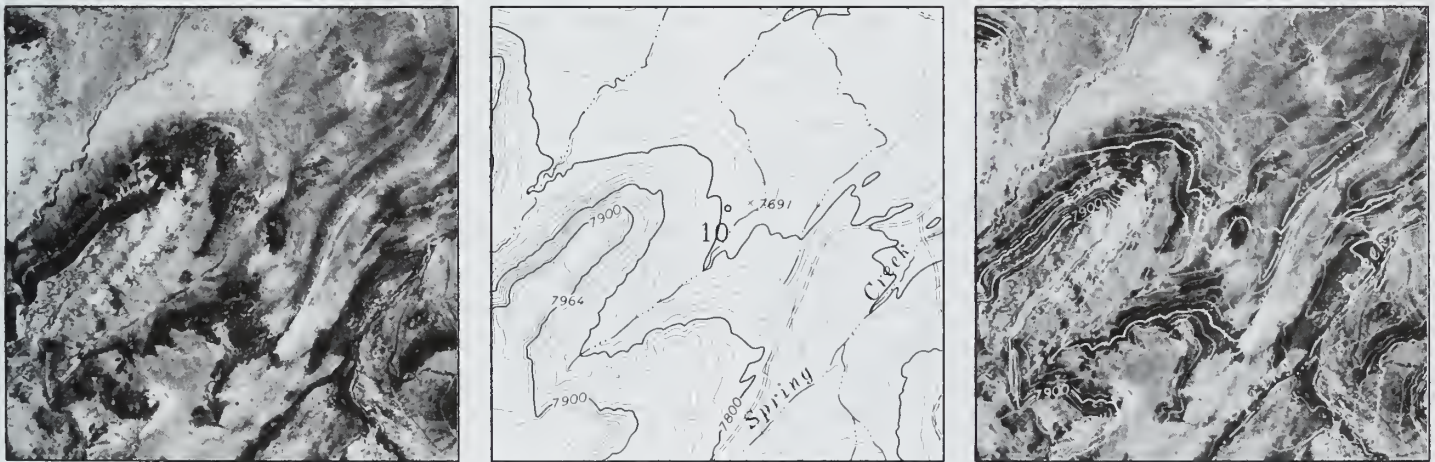


Figure 7. An example of one section (1 square mile) from the Jelm Mountain, Wyoming, orthophotoquad (left) and USGS 7.5-minute, 1:24,000 scale topographic map (center). The image on the right shows the orthophotoquad and topographic map superimposed, which creates an excellent resource mapping tool.

USGS 7.5-minute, 1:24,000 scale orthophotos have more image detail to assist in the transfer of data from aerial photos. Thus, resource data transfer and positional accuracies are better than when a

topo map is used for most natural features. When transferring field locations to a topo map with limited features, such as areas of low relief with no contours, errors can exceed 100 meters (320 ft).

Data Capture with Manual and Scan Digitizing Systems

System Description

The primary method for entering resource coordinates into a GIS is to manually digitize a map using a digitizing tablet. These digitizing devices use GIS software to obtain control from coordinates plotted on the map. The mapping data are then traced into the spatial data base by using computer algorithms to adjust and interpolate feature coordinates. Most systems give on-line coordinates to check digitizer accuracy. The mapped feature attributes are entered from the keyboard into the data base. Manual digitizing is very labor intensive.

Scan digitizing technology, although still evolving, has recently gained popularity. Scanning requires coordinate control points to compute the scanned data coordinates. Scanners can be simple, inexpensive video cameras or computer text and image scanners. These scanners have optical and random electronic distortions that are difficult to remove. Cartographically accurate, large-format map scanners are becoming more available, along with microcomputer scanning software, to produce high-quality digitized and edited data (Figure 8). These scanners are available in some government agencies and through commercial sources.

Most scanning requires a large amount of editing either before and/or after the data have been scanned; however, raster to vector software has improved, reducing the amount of editing. Several commercial and public domain software systems are available to transform scanned data into useful spatial data with geographic coordinates. An example is Line Trace Plus (LTP) software developed by the U.S. Forest Service (USFS) and the Soil Conservation Service (SCS), which is used to produce Digital Elevation Models (DEMs) from mapped contour data. LTP can turn a scanned soil

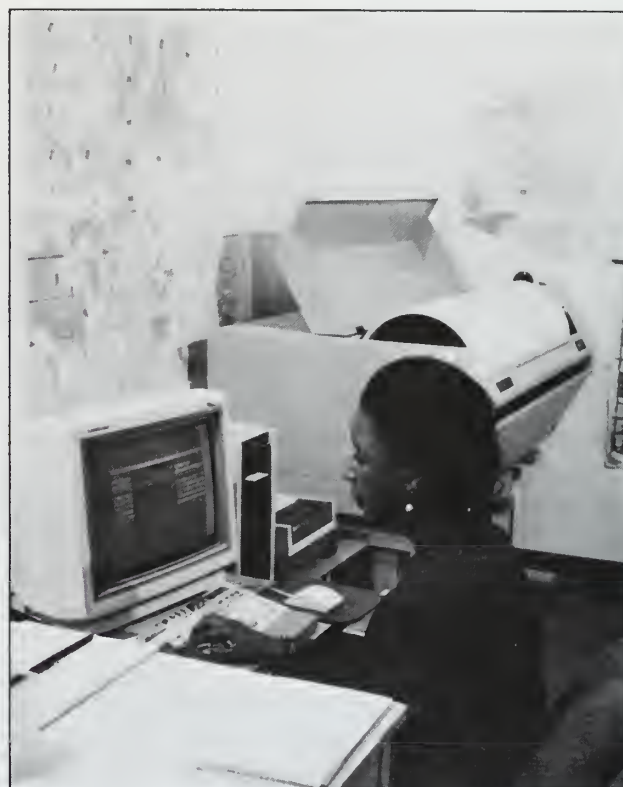


Figure 8. A high accuracy, digital scanner workstation used for automated map digitizing at BLM's Service Center in Denver, CO.

map into digitized vector data more efficiently than manual trace digitizing with a digitizing tablet (Figure 9).

Scanning data that are not orthogonal (positionally correct) generally cannot be corrected. Scanning timber types plotted on aerial photographs in high relief areas creates errors that are almost impossible to correct. Edge-matching this data is difficult and requires manual interaction. Any subsequent use of these data with correctly positioned data in GIS will immediately show errors. Scanning systems require very neat and clean map

data and work best with single theme mylar overlays having data plotted in dark narrow linework. Overlays with very detailed data, long attributes, and attribute leaders are difficult to scan and edit into a clean GIS data base. It may be useful to test a small part of the data prior to scanning a large project.

Main Uses

Manual or scan digitizing is normally used for digitizing existing mapped resource data overlays. The quality and neatness of the data should be checked prior to digitizing to minimize errors. Correcting digitizing errors can double the data entry costs.

Resource Mapping Potential

Manual digitizing is the main source of digital resource data for a GIS and can take from 2 to 40 hours per map overlay. Scanned digitizing is quickly supplementing digital resource data capture and works best when used on complex irregular line data, e.g., soils, wetlands, drainages, etc.



Figure 9. A cartographic technician manually traces linework with a digitizer (digital tablet).

Existing Digital Cartographic Data

Digital Terrain Data (Raster)

System Description

Two DEM formats are currently available from USGS in the United States. A third DEM format, 1:100,000 (100k) scale, 30- x 60-minute, 2 arc-second cell size (approximately 60 meters), is under production.

The 1:250,000 (250k) scale DEMs cover the entire United States except Alaska. This raster data set has a 3 arc-second cell size (approximately 90 meters) and is available in 1° by 1° degree blocks. The original data were created by the Defense Mapping Agency (DMA) from 250k topographic maps. DMA produces similar digital terrain data called Digital Terrain Elevation Data (DTED) in non-U.S. areas.

Larger scale, 7.5-minute-format DEMs are available covering many USGS 7.5-minute, 1:24,000 (24k) topographic map units (Figure 10). These DEMs have a 30-meter (96-ft) cell size with ± 7 -meter (± 22.4 -ft) vertical accuracy, approximately

the accuracy of a 12.5-meter (40-ft) contour map. Some DEMs have a ± 15 -meter (48-ft) vertical accuracy. (See the Aerial Photography, Orthophotography, and Photogrammetric Based Systems for the production of DEMs.)

Main Uses

DEM data can be used in any automated terrain analysis software that processes cell data. DEMs (7.5-minute) can be used for slope and aspect mapping, intervisibility models, terrain data for GIS models, and terrain correction for orthophotograph production. DEMs are used as a GIS surface model and when combined with geologic drill hole data, overburden can be calculated. DEMs can be used for medium-scale resource applications, but more detailed terrain data may be required for individual tract or site evaluation. The 250k or 100k DEMs can be used for terrain geometric corrections for SPOT and Landsat data, for intervisibility of radio transmission signals, for the production of digital shaded relief, etc.

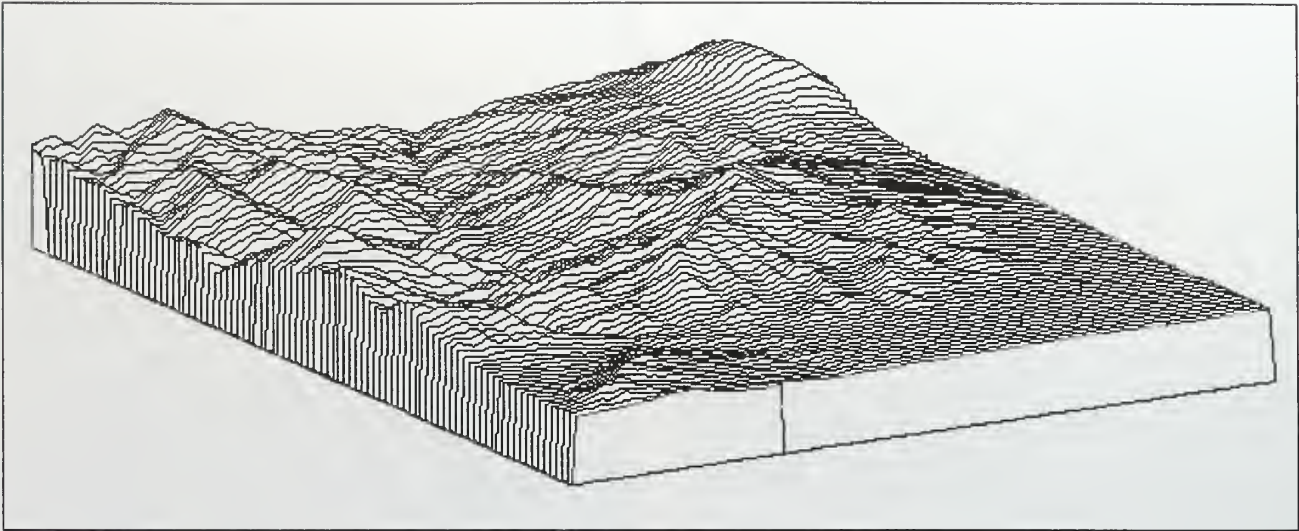


Figure 10. A 3-dimensional perspective drawing from a scanned Digital Elevation Model (DEM).

Resource Mapping Potential

DEMs are gaining in popularity as a terrain analysis tool, but great care must be taken in interpreting the output products. DEM cells or elevation posts are generalized and represent only the average terrain over the 30-, 60-, or 90-meter cell area. Some DEM production techniques enter error or unique characteristics into the digital product, which can include striping, patching, and stairstep patterns. All DEM output products should be treated as interpretative tools that generally represent the terrain. Slope maps produced from DEMs can be used for general route location, but specific terrain interpretation should be obtained from large-scale topographic maps and/or field work.

Digital Vector Data

System Description

USGS produces Digital Line Graphics (DLG) in two formats. Complete USGS, 1:100,000 (100k) scale DLGs are available for the United States, excluding Alaska. The 100k DLGs have transportation, hydrography, and boundaries digitized. Digitizing of contours and PLSS land lines has been initiated. These DLGs are digitized from the national 100k topographic map series. This data base was used for one of the U.S. Census TIGER file's data source (see below) and were also used to produce the Environmental Protection Agency River Reach data base.

The 7.5-minute DLGs are produced from 1:24,000 (24k) topographic maps by USGS. Only a small percentage of the United States is completed, but base maps will be converted to DLGs over time. The 24k DLGs include the PLSS, boundaries, hydrography, transportation, hypsography, manmade features, and survey control data for the 7.5-minute mapping series. These data will support national map revision and map production generation.

Main Uses

While existing DLGs are beneficial for GIS digital data bases, the proposed DLG-E (enhanced) format will support full GIS spatial analysis. As DLG data become available, they can be used as a digital base for resource value-added information.

Resource Mapping Potential

Very few 24k DLGs have been produced and they are especially scarce in BLM's prime interest areas in the Western U.S. If funding is available, USGS, with BLM's and other agency's support, plans to produce DLG-E for the entire U.S. over the next 5 years. This optimistic projection would give BLM a digital base map that could be maintained and enhanced into Resource Base Data (RBD), with BLM-specific attributes on most map features. All land management GIS activities require digital RBD for full and economical GIS applications. If RBD are unavailable, a similar base data set will have to be produced for each project. USGS will enter into cost-share and work-share cooperatives to accelerate

both in-house and contracted DLG production. Most DLGs have to be modified for resource analysis use in a GIS.

Topologically Integrated Geographic Encoding and Referencing Data

System Description

Topologically Integrated Geographic Encoding and Referencing (TIGER) files were produced and are maintained by the Bureau of the Census as the base data for the collection and analysis of the 1990 census. These data were based on the 100k DLGs enhanced with the older format, detailed urban census data. Because of mixed data sources, positional accuracy is difficult to evaluate for TIGER data. For rural areas, TIGER data should equate to the accuracy of USGS 100k DLGs. Much of the data in urban areas has less than 100k positional accuracy because street addresses are spread along an entire block between two nodes for privacy reasons.

Main Uses

TIGER files are excellent for socioeconomic data analysis and can be used for population related GIS analysis. TIGER files are available for the entire U.S. on inexpensive CD-ROM computer disks.

Resource Mapping Potential

Resource use is limited to population analysis because census statistical data has been generalized

in rural census tracts to maintain individual privacy. There is some potential for wildfire risk analysis for populations located near public lands. General socioeconomic modeling can be performed for recreation and mineral resources demand.

Digital Chart of the World

System Description

Digital Chart of the World (DCW) is a DMA digital data base generated primarily from the 500k scale Operational Navigation Chart (ONC) series. DCW includes 1,000-foot contours, major transportation routes, populated places, major hydrography, and international boundaries digitized in the DMA Vector Product Format (VPF) for use in spatial systems. Positional accuracies are equal to the source ONC data base, 2,000 meters horizontally and 650 meters vertically.

Main Uses

This worldwide data base was created for Department of Defense (DOD) requirements, but should be a useful base for regional natural resource needs. It is available on inexpensive CD-ROM computer disks.

Resource Mapping Potential

The DCW has limited resource mapping potential due to its small scale. DCW has some potential as a digital flight planning/management tool, especially when large regions of the country are analyzed.



Aerial Photography, Orthophotography, and Photogrammetric Based Systems

Aerial Photographs as a Resource Data Collection Tool

System Description

Aerial photographs are excellent field mapping and data interpretation tools. Substantial amounts of resource data can be interpreted and mapped directly on aerial photographs in the office prior to field verification. In some cases, aerial photographs are the only intensive mapping tool for pretyping resource data, such as soils, vegetation, wetlands, and geology, that is spread over large areas. Aerial photos are especially useful when the resource data don't have a definite line or polygon on the ground, but areas of transition that cannot be seen easily in the field.

Aerial photography is also an excellent data collection tool; however, it contains numerous image distortions requiring special geometric corrections, and therefore cannot be considered a true positional tool. These corrections can be obtained through photogrammetry, which is the science of making true measurements from aerial photography, or the data can be transferred to orthophotos. Photogrammetry is more precise, but requires costly stereoplotter equipment. Manually transferring data from photographs to maps is labor intensive and may be less precise.

Stereoscopic aerial photography is a key geospositional tool, but correct locations can only be produced using orthophotos or stereoplotters with ground control coordinates produced from one of the other positional tools. For the ground coordinates to be identifiable in an aerial photo, they are normally preselected and paneled prior to the flight. Panels are strips of white plastic, normally in the form of an X, placed on the ground at control points that need to be seen in the aerial photos. Some resource reference data, such as section corners or small archeology sites, can be paneled prior to a flight so they are easily identifiable on the imagery.

The panel locations may require ground surveys or GPS surveys to obtain coordinates for the photogrammetric model setup.

Main Uses

Most field vegetation and soil surveys use aerial photos as their field base. Almost any resource data can be plotted on aerial photos, because of the large amount of ground detail and easy correlation with the user's location. Aerial photos are used in photogrammetric stereoplotters to produce orthogonally correct maps or orthophotos. The stereoplotters can be used as a data collection tool for soil surveys, timber, wildlife habitat, or many other inventories. When used in simple stereo viewing devices, photos give the interpreter a three-dimensional view.

Resource Mapping Potential

Although one of the strongest natural resource mapping tools, aerial photos, especially those on color and color infrared film, have been underutilized in land management activities. While resource-scale (1:24,000 - 1:31,680) aerial photos have been cost effective for identifying and mapping resource data, resource specialists use less than 50 percent of the potential capability of this tool due to the lack of training and experience. Aerial photos can be used to map most of the important oil and gas well field activities without visiting each feature to be mapped as required for GPS mapping. Many features are difficult to access on the ground, such as a revegetated pipeline, and real-time aerial mapping doesn't allow enough identification time. Aerial photos, when used with other geo-positioning tools such as topo maps, orthophotography, digital orthophotos, and photogrammetry, are some of the best tools for identifying and mapping field resource data.

There have been two national aerial photo programs led by USGS, with cooperators from several Federal agencies and some state governments. The first was the National High Altitude Program (NHAP) which used Lear jets flying at 40,000 feet with two aerial cameras. One camera had an 8-1/4-inch (210-mm) focal length taking 1:58,000 color infrared (CIR) aerial photos, and the other camera had a 6-inch (153-mm) focal length taking 1:80,000 black and white (B&W) photos. The 1:80,000 photos were called quad-centered because every other photo was centered on a USGS 7.5-minute topo map, and were used to produce most of the orthophotoquads in the U.S. The second cycle of

the program, started in 1989, was renamed the National Aerial Photography Program (NAPP) and used a 6-inch (153-mm) focal length camera taking 1:40,000 B&W and CIR photos, dependent on the cooperator's requirement (Figure 11). These photos are referred to as quarter quad-centered photos because every other photo is centered on the quarter of a USGS 7.5-minute topo map. The third cycle will begin in fiscal year 94 using the same specifications as the second cycle, except only B&W film will be used. The aerial photos from this cycle are planned to be used for the production of digital orthophotos, discussed later in this section.

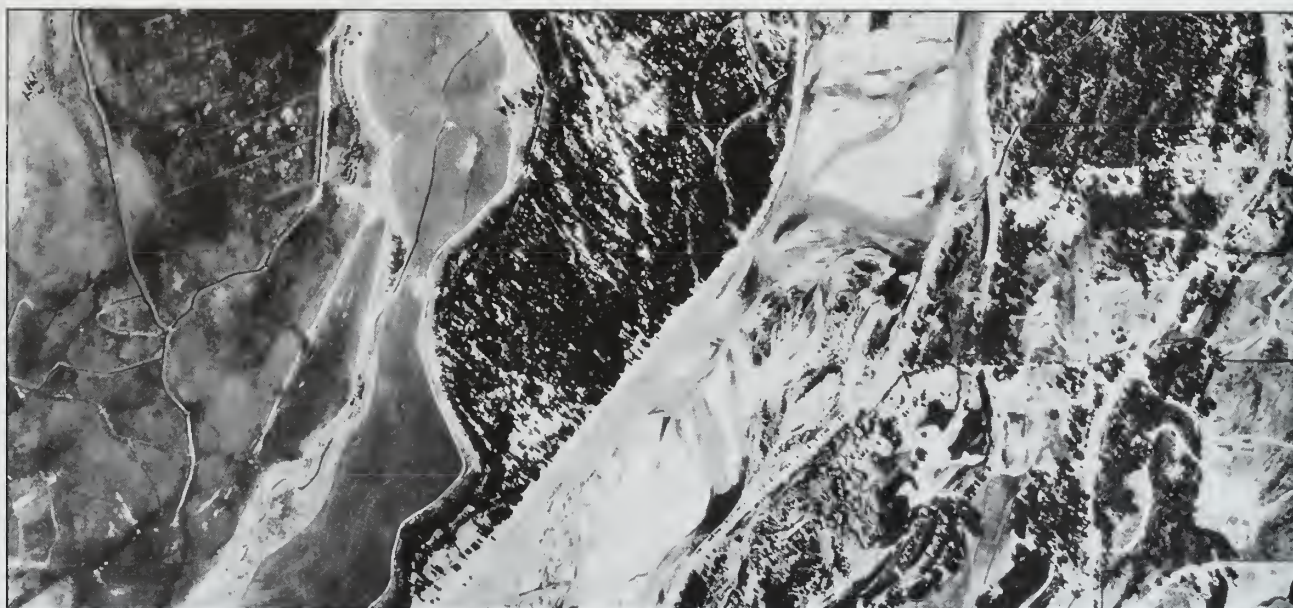


Figure 11. A black and white copy of a portion of a color infrared NAPP aerial photograph of the Snake River in Jackson Hole, Wyoming. NAPP is available nationwide.

Single Photo Resection

System Description

Computer-adjustment software has been created in the past few years to digitize locations directly from nonstereo aerial photography. Some software programs use terrain models to assist in a geometric correction of digitized data. This technique is not recommended to obtain accurate coordinates. The process works better with very high altitude or space-based imagery, which has little terrain distortion in areas of low terrain relief. The same location distortions exist when digitizing from an unrectified aerial photo.

Main Uses

Single photo resection can be used for digitizing or mapping directly from a single nonstereo aerial photo. This technique has been used on the very flat North Slope of Alaska because it met the positional accuracy requirements of the project.

Resource Mapping Potential

The potential use of single photo resection mapping is very limited because it cannot meet NMAS in most situations. Single photos have been used for map updates and maintenance, but significant errors have been identified in some map products.

Photogrammetric Stereoplotters

System Description

Photogrammetric stereoplotters are precision optical instruments which allow the user to view a stereoscopic model of the earth's surface and then map the interpreted data from the photo image. If detailed survey ground control is added to the model, precise ground measurements can be obtained. When the ground control is tied to geodetic control, direct geographic coordinates can be collected from the stereoplotters. Analog stereoplotters normally use direct image viewing with optical and mechanical adjustments to change the stereo image into a distortion-free, 3-D model. These 3-D models can be scaled and mechanically leveled to fit the earth's surface and produce geographic measurements in x, y, and z. Newer, fully analytical stereoplotters use computers to assist with setting up models and adjusting the stereo model to true ground coordinates. Because of their easy setup and increased accuracy, analytical stereoplotters are replacing the older analog stereoplotters (USFS, 1985).

New *digital photogrammetry*, using only a computer workstation with a high-resolution screen, is rapidly expanding in land management applications and does not require large stereoplotter instruments. These systems require scanned stereo aerial photography and the same ground control as traditional photogrammetry. They are very efficient for collecting elevation data and can be used to produce digital orthophotos. Digital photogrammetry's cost is still prohibitive for everyday resource activities, but costs should decline with new computer technology.

Several photogrammetric devices are available for resource data mapping, including:

- **Simple Stereo Transfer Equipment**—These instruments optically merge stereo aerial photographs with an existing map. The map features are used for model setup registration. Accuracy is limited to the base map accuracy and ability to register the photos to the map. Data are then transferred to the registered base map. Model setup has to be continually adjusted to maintain registration and is very difficult in areas of moderate or high relief, little image, or limited base map detail.
- **Analog Optical Stereoplotter**—This stereoplotter requires physical adjustment of mechanical gears and optics to obtain model setup. The stereo model image is viewed through binocular optics. These devices draw the output map through the use of scale-adjustable pantograph.
- **Analog Optical Stereoplotters With Digital Data Capture**—This is the same instrument as above, with digital encoders and computer software added to assist in model setup and digital data capture. This device still requires manual adjustments for model setup, but can produce direct, digital, spatial data bases for both planimetric and/or vertical data.
- **Analytical Stereoplotters**—This stereoplotter uses digital computers to assist in the mathematical model setup (Figure 12). Adjustments for model setup are performed automatically and model statistics can be generated to evaluate accuracy. The output may be a digital data base or a map drawing produced by a pen plotter.

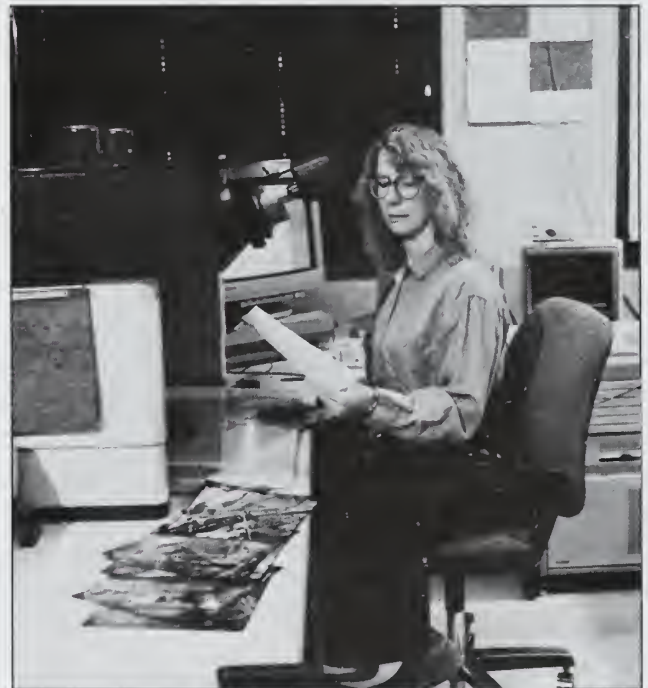


Figure 12. A professional cartographer uses an analytical stereoplotter in automated engineering map production.

- **Digital Photogrammetry**—This developing technology uses scanned aerial photographic images on a computer display for the photogrammetric process. Ground survey control is still used, but the expensive stereoplotters used for analog and analytical photogrammetry are not required. All input and output data are digital. Images can be acquired in a number of ways, such as by scanning film aerial photography, using aerial scanners, or using satellite based, remotely sensed, Landsat or SPOT images. Digital photogrammetry has high potential to produce DEMs, digital contours, and planimetric maps. Because low-cost computer workstations can be used for this technology, it will be available for more resource mapping applications in the future.

All photogrammetry requires detailed ground measurements for control. These measurements are normally obtained through ground control surveys, but more recently have been derived from satellite positioning devices. All photogrammetric control points must be identifiable in photos. Ground panels can be used to mark the control points prior to the flight to obtain photos.

Main Uses

Direct viewing and mapping of resource data on stereoplotters has been underutilized by resource managers, specialists, and scientists. Use has been

limited primarily because of the expensive equipment and special expertise required to set up and operate a stereoplotter. There has been some use in geologic interpretive mapping (Pilmore et al., 1981) and in wildlife habitat/wetland mapping by the U.S. Fish and Wildlife Service. Use will increase as digital photogrammetry evolves and the technology is placed into more users' hands.

Accuracies from photogrammetric systems can vary greatly due to the many parameters involved with mapping. The chart below shows estimated ground positional accuracies of products produced with photogrammetry.

Resource Mapping Potential

Photogrammetry has not been directly accessible due to the high level of expertise required, but has supported resource mapping requirements extensively for several years from behind the scenes. Photogrammetry will remain the most effective system to produce engineering-scale, 3-D base maps, DEMs, and topographic maps. Digital photography will have a great impact on the direct resource access to photogrammetry capability. BLM in Alaska is performing photointerpretations, using color infrared aerial photography and mapping survey meander lines with an analytical stereoplotter. The plotter produces turn point coordinates on the meander line as the hydrography is interpreted (Nakazawa and Vanderlinden, 1986).

| Type | Class | Source | Scales | Est. Accuracies |
|--------------------|--------------|-------------------------------------|-------------------|-----------------|
| Engineering Scales | Large-Scale | Special Aerial Photos | <1:20,000 | ±2 cm to 1 m |
| Resource Mapping | Medium-Scale | NAPP or Resource Aerial Photography | 1:20,000-1:62,500 | ±2 m to 10 m |
| High Altitude | Small-Scale | Lear Jet or U-2 Aerial Photography | >1:62,500 | >10 m |

Optical and Digital Superpositioning Systems

System Description

Several commercial vendors offer stereoplotters capable of overlaying (superpositioning) digital data bases and imagery simultaneously, thus giving the user the additional intelligence of the existing data base while performing photo interpretation. Digital superpositioning systems have recently been decreasing in cost.

Main Uses

These superpositioning systems are most commonly used for change detection, e.g., detecting and updating the data base for new roads on new aerial photos. Sophisticated uses can be applied, such as displaying interpreted drill hole geology to the surface expressed on color aerial photography to better map fault lines (Pilmore et al., 1981). Other uses could include superimposing vegetation type maps from GIS files onto new aerial photos to update wildlife habitat or wetlands. The output will be in geographic coordinates of the existing data base. Satellite imagery superpositioning can greatly aid the integration of resource data analysis. USGS uses a commercial digital system to both produce and update digital topo maps (DLGs) from digital orthophotos (Figure 13).

Resource Mapping Potential

There is a very high potential for increased use of digital superpositioning systems in BLM and other resource management agencies. BLM's ALMRS/Modernization system includes this capability in the digital data capture subsystem, as do

most commercial GISs. The ability to overlay a raster aerial image with vector resource data provides the unique capability to digitally edit and accomplish quality control of the original data base. The main advantage with superpositioning is the ability to identify mapping interpretation and positioning errors not known to be in the data base, such as when the forestry clear-cut was not depicted in its correct location or size. Management may not want to know these historic errors exist in older resource data bases or address the resources necessary to make the corrections.



Figure 13. USGS digital superpositioning system workstation operation using commercial GIS software for Digital Line Graphic (DLG) production.

Combined Interpretation, Map Compilation, and Spatial Analysis

System Description

The increased use of computers in photogrammetry has allowed several operations to be combined into one system. With such a system, the operator can interpret photos, map the location, and then spatially analyze and model data. The Geological Division of USGS in Denver has been developing and refining this technique for over 15 years (Pilmore et al., 1981). The results of interpretation and analysis are greatly strengthened when digital imagery and GIS spatial modeling are combined.

Main Uses

BLM in Wyoming has developed a coal mine production verification system using photogrammetry with ground control in combination with a coal

drill hole geologic data base to produce precise 3-D models of the coal geologic structure before and after mining and production volumes (Keating, 1992). Parcel volumetric analysis is easy when parcels are overlaid digitally with lease boundaries produced from GPS coordinates of cadastral survey corners and geologic structure.

Resource Mapping Potential

There is very high potential for resource use of systems that combine positional tools such as photogrammetry with cartographic modeling used in GIS. This technology will expand rapidly with the use of new computer tools and standard data bases, such as cartographic base data and digital orthophotography.

Orthophotography and Digital Orthophotos

System Description

Orthophotographs, orthophotoquads, and orthophotomaps are aerial photos with distortions and displacements removed using special optical or

digital equipment and software with ground control measurements and elevation data from DEMs (Figure 14). They have most of the visual benefits of aerial photos plus the positional accuracy of a map, making them an excellent geo-positioning tool

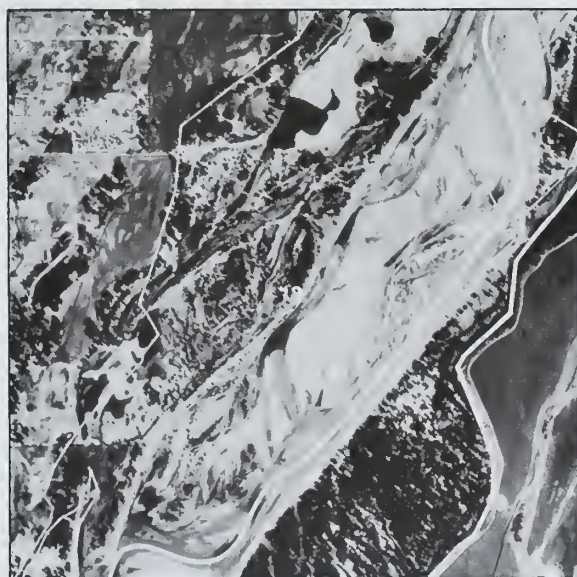


Figure 14. On the left, an orthophoto enlargement produced from 1:40,000 scale NAPP aerial photograph. The cadastral survey landnet registers to the image because the image was scale and displacement corrected. On the right, a digital orthophotoquad is displayed on a workstation for automated map update and maintenance.

for natural resource applications. Orthophotos are produced to a base datum and referenced to geographic coordinates. Field data can be visually transferred to the orthophoto and then digitized into a GIS. Orthophotos can be produced as large-scale project base maps for engineering and landscape design, and as 7.5-minute, 1:24,000 scale companion products to USGS topographic maps. In addition, satellite images from SPOT or Landsat can be processed into hard-copy or digital orthophotos.

- **Large-Scale Orthophotomaps**—Orthophotos produced at scales larger than 1:12,000 are excellent tools for recreation site development. Both BLM and USFS have used large-scale orthophotos for recreation site landscape planning and engineering. Orthophotomaps that include contours and land ownership information are most useful. Color orthophotos allow the user to identify and map each tree or shrub for landscape design. Geographic coordinates can be produced for the entire site plan.
- **National Program Orthophotoquads**—Orthophotoquads are orthophotos produced in the format and scale of USGS 7.5-minute, 1:24,000 scale topographic maps. Thousands of orthophotoquads have been produced by USGS through cooperation with BLM, USFS, SCS, States, and other agencies. Several entire states are covered, but USGS has not produced these as a standard national series. These orthophotoquads were produced in the 1970's and 1980's primarily from 1:80,000 scale aerial photos taken at high altitude from a Lear jet and also from NHAP aerial photography.
- **Quarter Quad and Digital Orthophotos**—A new national initiative for 1:12,000 and 1:24,000 digital orthophotos has been started by SCS and USGS with cooperation from BLM, USFS, DOD, and other Federal and State agencies. Prototypes and some early maps have been produced in quarter-quad-format (1/4 of a USGS topographic map), 1:12,000 scale, digital and printed orthophotos from 1:40,000 scale aerial photos produced by the multiagency NAPP cooperative program. These digital image map products

are very useful for digital map updates, direct image interpretation on a computer display, and GIS use. Survey plats and land ownership status can be displayed directly onto the digital images. Existing base map data and natural resource data can be superimposed on the digital display for accuracy and currency comparisons. Errors or data base maintenance can be performed directly with on-screen digitizing. Hard copies can be printed for field use. Once the orthophoto is produced, it can be easily updated using new aerial photography and the same DEM and ground survey control points. Plans are to produce digital quarter-quad- or orthophotoquad-formats for the entire U.S. with aerial photography from the second cycle of NAPP starting in fiscal year 94.

- **Space Image Maps (Space Orthophotos)**—The same computer systems used for orthophoto production can be used to produce terrain-corrected, Landsat and SPOT images for use as large-area orthophotos. The move to digital mapping systems has eliminated some of the distinction between satellite remote sensing and photogrammetry. Differences are limited to the resolution of the image detail and the amount of ground area covered in an image. Space images have been used as small-scale digital orthophotos for many years. (For additional information refer to the Satellite Remote Sensing Systems section.)

Main Uses

The main advantage of orthophotos is that they are as current, positionally correct map or aerial photo substitutes. Orthophotos are one of the best tools to map and obtain accurate coordinates on resource data for GIS use.

Resource Mapping Potential

Orthophotos have been around for over 30 years and they are just reaching many resource users. In the past, too much image quality was lost in the orthophoto production process. Recent hardware and software enhancements, including the digital orthophoto, have greatly improved the product quality while reducing production cost. Future improve-

ments include making the orthophoto more available to the resource users. The digital orthophoto will add tremendous flexibility and provide for quick map updates, and map maintenance can be performed on the computer screen with the cartographer tracing new map features into a digital data base. In the future, orthophotos will be important

quality control tools, by overlaying current orthophotos over older resource data. The resource specialist will be able to assess the positional correctness, currency, and data interpretation accuracy of the old data base at the same time, while using this tool to edit and rectify any problems with the data.

Other Aerial Imagery Systems

Aerial Video with GPS

System Description

Television video systems can be mounted in aircraft and flown for near real-time imaging and interpretation (Figure 15). Video has limited geo-positioning capability due to difficulty in removing distortions from the analog video image. Video cannot be used for precise mapping purposes, but real-time differential GPS (DGPS) can provide geographic coordinates to enhance the video frame location. It can also provide the flight-line flown by the aircraft. The image swath center can vary up to ± 30 meters when flying at 1,500 meters above ground level (Evans, 1992). Information can be extracted from a video frame and superimposed onto orthophotos for increased positional accuracy.

Aerial video can use a single GPS receiver, but accuracies can exceed 100 meters without a second differential GPS unit on a base station and postprocessing of data. In order to obtain the highest quality coordinates, in the ± 10 meter range, another GPS receiver needs to be located at a control survey marker. This GPS unit would have to

transmit positional correction information to the aircraft. A computer in the aircraft uses the two GPS's data to calculate the adjusted coordinate; this position and the precise time is then merged with the video image.

Main Uses

Resource agency law enforcement programs have used video imaging with differential GPS to document ground activity locations with the image position geographic coordinate superimposed on the video image. The user can be relatively assured that the coordinate falls within the video frame coverage, depending on the focal length, altitude and attitude of the video camera, DGPS procedures, and correct placement of the GPS antenna on the aircraft.

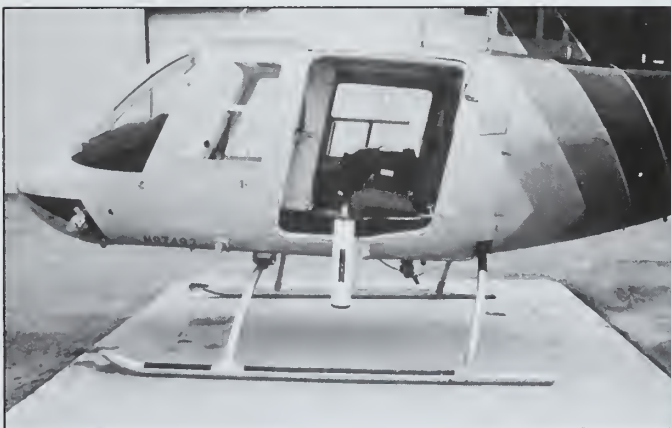


Figure 15. An aerial video camera mounted on a Bell 206 Jet Ranger helicopter and mounted in the luggage compartment of a Cessna 182 light aircraft. Photographs provided by the USFS.

Resource Mapping Potential

Aerial video imaging is very useful for quick identification and mapping of features and phenomena that change or move, such as a flock of geese; evaluation of a natural resource catastrophic event, such as a flood or volcanic activity; and evaluation of manmade disasters, such as a large oil spill. The techniques also work well for events that occur over time, and require both the location and the time sequence of the event. Positional accuracies fall below most resource mapping requirements, but the ability to collect real-time pictures enhances use of aerial videos for emergencies or time-sensitive situations.

Airborne Thermal Infrared

System Description

Thermal Infrared (IR) scanners are devices that collect ground reflective temperatures in the thermal IR part of the electromagnetic spectrum. Two types of scanners are available, the most common is a sensor that captures relative temperature differences and a more complex, costly, and calibrated sensor that provides actual ground temperatures.

Current operational IR systems at the National Interagency Fire Center (NIFC) in Boise, Idaho capture a frame of thermal IR imagery from a monitor in the aircraft. A trained IR technician interprets the print of graytones representing hotspots on the ground. Location is added from maps and the annotated print is dropped to the ground fire crews. Airborne image scanning use is expected to increase in the future, especially with increased use of digital image systems. Handheld, low-resolution, framing digital scanner cameras are available for less than \$1,000 and high-resolution IR images from aircraft can now be obtained. DOD and NASA scientific investigations have developed the more sophisticated scanners. Recent thermal IR scanner technology has reduced distortions and increased resolution and sensitivity of the image. Sensors have been combined with GPS and are estimated to have accuracies of ± 25 meters (80 ft.) for their ground location.

Main Uses

Wildfire situation mapping has been the mainstay of operational thermal scanning. Remote sensing analysis has used thermal IR scanners for locating large mammals, mapping thermal springs, perform-

ing residential and industrial heat loss studies, identifying thermal pollution, and mapping geology, including lava flows.

Resource Mapping Potential

Airborne thermal scanning has been used to map wildfire locations and extent for many years, but with the addition of DGPS and digital orthophotos, precise fire situation maps can be generated in minutes. A new system, the Forest Service's Firefly, is under operational testing at NIFC. Firefly uses a high-performance thermal scanner with a computer to capture the wildfire images, combine it with GPS coordinates, superimpose map features, and then transmit the image to a computer at the fire site headquarters. An overlay of the hotspots can be plotted for the fire situation map. Future applications include the identification and mapping of active pipelines in an oil & gas field, underground thermal spring recharge of lakes and streams, thermal pollution, ground temperature differences showing near surface geological differences, and locations and activities of nocturnal wildlife.

Other Aerial Systems

Other potential aircraft-based systems collect data on the earth's surface, but are not readily available as positional devices.

- **Airborne Multispectral Scanners**—These scanners are similar to satellite sensors that map both the visible and infrared parts of the electromagnetic spectrum, but are mounted in aircraft. NASA has several systems that are packaged to be placed on various types of aircraft. NASA uses an ER-2, a civilian version of the military U-2 spy-plane, to fly high-altitude resource imagery. NASA aircraft are available for scientific investigations on a reimbursable basis.
- **Airborne Laser Profiling**—This technique can be used to produce elevation control for mapping operations, especially with DGPS. Laser profiling has seen limited use since the late 1960's for mapping height-above-ground aircraft data.
- **Synthetic Aperture Radar (SAR)**—With digital geometric corrections, SAR can be used to locate many types of resource data,

but it is costly and not widely available. SAR has been useful in geologic, surface geometry, and a few archeological applications. Recent remote sensing applications have used near ground (helicopter) and ground base radar to capture near surface differences in soils and geology.

- **Geophysical Airborne Data Collectors**— These collectors gather many types of data, and can be used to measure and map the earth's gravity and magnetic fields. These systems are used in geodesy, which is the science of measuring both the size and shape of the earth, and geology to locate mineral deposits.

Satellite Remote Sensing Systems



For natural resource activities, remote sensing from space has the potential to add synoptic coverage as a common thread of positional sciences. In addition to being an inventory tool, remote sensing can be used with superpositioned, geometrically corrected, space imagery with existing digital GIS data, as both a data maintenance and quality control tool. Editing of superpositioned space imagery with vector GIS data on high-resolution color graphics workstations will provide a visual review of change detection for very large areas. The effectiveness of this new technology could be increased by using artificial intelligence to alert the user to potential change.

There are still problems with obtaining accurate worldwide base maps for geometric corrections, but the United States has excellent coverage. Full positional correction from only the satellite and sensor data is developing, but it may be years before imagery data directly from the satellite platform are accurate enough for resource use without extensive postprocessing. Most remote sensing system analysis software bases geometric transformations on map coordinate Ground Control Points (GCPs). More recently, digital terrain data has been added to remove most image distortions. There have been exceptional positional accuracy results in terrain-

corrected SPOT Panchromatic (SPOT PAN) and the Landsat Thematic Mapper (TM) data, easing image edge-match problems and correlation of individual pixels to their ground locations.

The chart below compares the mapping accuracy and estimates the maximum mapping scales of various sensors for resource work. The use of digital satellite imagery as a geo-positioning and mapping tool has greatly accelerated due to increased availability of low-cost workstations with imagery processing capabilities. This rapid change in remote sensing technology availability will allow for more diverse applications in the field. In the past, the high cost of large computer systems and complex analysis software forced agencies to centralize remote sensing functions. The new image processing systems will allow for decentralization of the analysis functions. In order to meet this increased demand, the primary data providers, Landsat and SPOT, have become innovative in packaging satellite data in smaller, less costly units. Remote sensing software analysis capabilities are merging with both digital photogrammetry and GIS applications, making digital imagery analysis available to more users. The accessibility of digital data is limited to the three space imagery systems discussed in this section.

| Sensor Type | Pixel Size* (meters) | Maximum Potential Scale | Position Resolution (meters) | Accuracy** (meters) |
|-------------|----------------------|-------------------------|------------------------------|---------------------|
| MSS | 70 | 1:100,000 | ±80 | 70-150 |
| TM | 30 | 1:100,000 | ±30 | 30-70 |
| ETM (est.) | 15 | ±1:50,000 | ±15 | 15-50 |
| SPOT MS | 20 | ±1:50,000 | ±20 | 20-50 |
| SPOT PAN | 10 | ±1:25,000 | ±10 | 10-24 |
| Sojuzkarta | Photographic | ±1:25,000 | ±5 | unknown |

* A pixel (picture element) is the minimum resolution cell in an image represented on the ground.
 **Although several test studies state that mapping accuracies of less than 1 pixel can be achieved for that sensor, any positional measurement results smaller than the sensor's pixel ground size should be treated as approximate and only available in very rigorously controlled situations.

Landsat

System Description

Over the last 20 years, remote sensing scientists have been making geometric corrections of the Landsat Multi-Spectral Scanner (MSS) image data using map and image identified coordinates for GCP. Recent estimates of positional accuracy of MSS using GCPs have produced residual errors of ± 0.23 and ± 0.26 pixels as reported by Welch et al., 1985. Welch also reported that the data from MSS could meet NMAS for 1:50,000 scale or smaller maps and are well suited for image maps of 1:100,000 scale. However, accuracies better than ± 80 meters for resource data are very difficult to obtain and result in 1:100,000 scale NMAS map products for resource use.

The Landsat higher resolution Thematic Mapper (TM) sensor has been tested to positional accuracies as high as 20 meters Root Mean Square (RMS) (Goodenough, 1988) with high potential for use in a GIS (Figure 16). Swann et al., 1988, stated that with 4 to 6 GCPs per scene, geometric corrections in the subpixel range could be obtained. Therefore, TM data would approach 1:50,000 scale mapping accuracies.



Figure 16. A black and white copy of a Landsat TM composite image of Gallup, New Mexico. Clouds and cloud shadows can be seen in the lower right hand corner.

Ehlers and Welch, 1987, reported accuracies for TM RMS using DEMs in the ± 42 -meter range, and accuracies as high as ± 25 meters for withheld test points from 1:24,000 scale maps using a first degree polynomial equation for adjustments. They also reviewed the potential to use only satellite sensor and platform parameters without reference to ground control points and stated, "However, it remains difficult to recover Universal Transverse Mercator (UTM) or geographic (latitude, longitude) coordinates without reference to ground control points." Their results indicate TM's accuracy is good enough for mapping at scales 1:100,000 and smaller. Ground resolution ranges from ± 30 meters for the visible and near IR imagery (not positional accuracy) to 120-meter resolution for thermal images. It is estimated that the Enhanced Thematic Mapper (ETM), planned for future Landsats, will have a resolution around 15 meters, which with GCP geometric corrections, should approach 1:50,000 scale mapping accuracies (USGS, 1986). Marvin et al., 1987, reported that a 2-km (6,400-ft) terrain difference could result in mislocations of up to 270 meters horizontally on image edges, and developed terrain adjustment geometric correction software that approached pixel-level accuracies in areas of high relief.

Future Landsat satellites will have a new sensor added to the existing TM sensor (Figure 17). ETM will be a panchromatic band spanning visible to near infrared at a 15-meter spatial resolution. Landsat data are available from EOSAT Corporation, Lanham, MD, or from EROS Data Center, Sioux Falls, SD, for Federal Government users. (BLM users should contact their remote sensing coordinator at the State Office or the Service Center.)

Main Uses

Landsat imagery has been used to manually and digitally interpret, map, and locate a large variety of natural and cultural phenomena that can be identified by their spectral reflectivity from the earth's surface. Landsat TM data has proved very beneficial to large-area vegetation studies where detailed inventories are not available. General vegetation cover type studies have covered millions of hectares at 30-meter cell size, with some studies covering

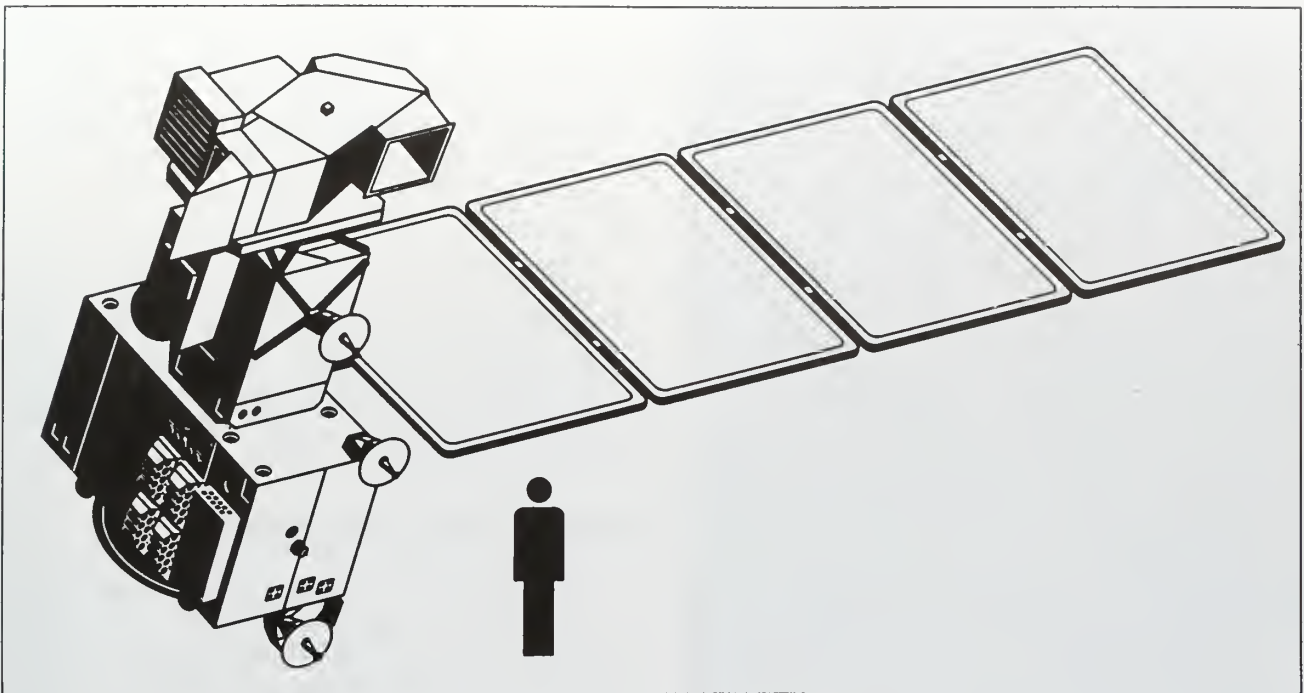


Figure 17. Future Landsat satellites will have the new Enhanced Thematic Mapper (ETM), which will double the resolution to 15-meter pixels (cells).

entire Western states for biodiversity modeling. TM data has been used to identify and map old-growth timber stands for habitat management for the entire Pacific Northwest region. Previous old-growth inventories terminated at the edge of the public lands. MSS has been mostly used for mapping vegetation and other natural resources with spectral characteristics that can be identified on the imagery. MSS suffers from the lack of spatial resolution, i.e., the limited size of a pixel greatly affects the resultant positional accuracy. MSS data have proven valuable because nearly two decades of historic data are available to analyze worldwide global change issues.

Resource Mapping Potential

The increase in spatial resolution from 80 meters for MSS to 30 meters for TM and 15-meter pixels for ETM should provide excellent future resource

mapping tools. ETM, on the next generation of Landsat satellites, should provide resource inventory and mapping capability to scales of 1:50,000 (USGS, 1986) which should assist in both rangeland and wetland applications. Demand for remote sensing capabilities is being revitalized due to increased availability of low-cost processing systems and improved data availability. Recently multiagency agreements have provided for statewide access to LANDSAT data in some states.

In October 1992, a new Landsat bill was signed into law which ensures follow-on Landsat satellites, places the Landsat program under DOD and NASA joint management, and removes the satellite operation from the commercial sector. The new law provides for lower image fees for the Government, university, and nonprofit sectors, and supports remote sensing value-added studies by small companies in the private sector.

SPOT

System Description

The French remote sensing satellite, SPOT, while new to the remote sensing scene, is quickly gaining popularity due to its spatial resolution. SPOT has a panchromatic (PAN) resolution of 10

meters and a multispectral (MS) resolution of 20 meters (Figure 18). Swann et al., 1988; Rodriguez et al., 1988; and Goodenough, 1988, report SPOT PAN positional horizontal accuracies in the ± 10 -meter range (x, y) and vertical accuracies of ± 7 meters (z). Konecny et al., 1987, appears to verify

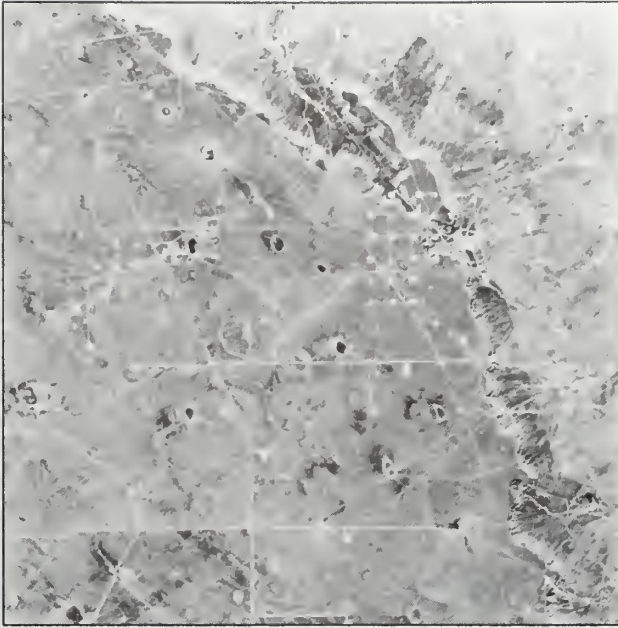


Figure 18. Geometrically corrected SPOT PAN satellite image example of Maljamar, New Mexico. The image covers a 7.5-minute area and reveals new roads, oil and gas well drill pads, pipelines, and rangeland grazing patterns.

these measurements and reports SPOT approaches a 1:25,000 scale topographic map's positional accuracy and 7.5-meter RMS digital terrain model accuracy when using analytical stereoplotters and 1:25,000 scale maps for control. Conservative estimates are that accuracies should follow more closely the accuracies of a 1:50,000 scale map when normal resource map production techniques are used with terrain geometric enhancements. The United States distributor for SPOT data is the SPOT Image

Corporation in Reston, VA. Federal government users can order SPOT images through the EROS Data Center in Sioux Falls, SD. (BLM users should contact their remote sensing coordinator at the State Office or the Service Center.)

Main Uses

SPOT use is similar to that of Landsat, but its increased spatial resolution should enhance SPOT as a resource mapping tool. This increased resolution can be used for change detection, such as new road, crop, and shoreline changes, and as a mapping update and maintenance tool.

Resource Mapping Potential

Both Rodriguez et al., 1988, and Goodenough, 1988, report that geometrically corrected SPOT satellite imagery can be used to verify previously mapped features and resource data such as timber clear-cuts, roads, and feature positional errors.

The potential value gained in using large-scale topographic maps and DEMs for geometric corrections may be lost in many worldwide locations that do not have maps at 1:50,000 scale or larger. In Third World areas, where remote sensing and mapping could be of the greatest value, positional accuracies would be much lower because of inadequate control. Other point positioning technologies, such as GPS or ISS, may eventually become cost effective when used for image identified GCPs. SPOT PAN stereoscopic coverage can produce DEMs and digital orthophotos if adequate ground control is available.

Advanced Very High Resolution Radiometer

System Description

Advanced Very High Resolution Radiometer (AVHRR) is on the Polar Orbiting Environmental Satellite operated by the National Oceanic and Atmospheric Administration (NOAA). AVHRR weather space images date from 1962, with the current satellite sensors initiated in 1978. The AVHRR system transforms four classes of data and transmits High Resolution Picture Transmission (HRPT) at a 1-km resolution to over 200 HRPT ground stations around the world. The four classes of AVHRR data are: (1) HRPT received in real-time by ground sta-

tions, (2) 4.4-km pixel Global Area Coverage, (3) delay transmission 1-km Local Area Coverage, and (4) analogy Automatic Picture Transmission (APT) for lower-resolution transmission to low-cost VHF ground stations (Hastings and Emery, 1992).

AVHRR 1-km pixel data can be geometrically corrected, but there is some loss of albedo and temperature detail as most software resamples the data. Any detailed monitoring would require geometric corrections for correct repositioning of the image. AVHRR's 3,000-km swath covers entire continents in a single pass.

Main Uses

AVHRR was primarily designed as a cloud and weather satellite sensor, but has become a valuable resource tool for large-area environmental mapping and monitoring (Figure 19). Its 1-km resolution limits the image detail but the daily and synoptic coverage increase its value. Hastings, 1992, described three categories of application. Meteorology applications include observations of general weather, cloud patterns, cloud temperatures, storms, and tropical cyclones. Oceanography applications include sea surface temperature, ocean currents, sea ice and sea ice edges, and land-water boundaries. Terrestrial applications include vegetation mapping and monitoring, snow cover mapping, desertification monitoring and research, volcanic eruption detection, and forest fire and smoke plume mapping. BLM used AVHRR 1-km multispectral data to map fire fuel potential for the Western United States. Monitoring of these data can reveal periodic changes in fuel potential.

Resource Mapping Potential

The geo-positional potential of AVHRR is limited to gross resource data as indicated above, but continuous daily coverage can identify changes that other sensors can map in greater detail. AVHRR data can reveal larger global change patterns and daily weather occurrences and monitor the seasonal vegetation green-up over large regions of the earth.

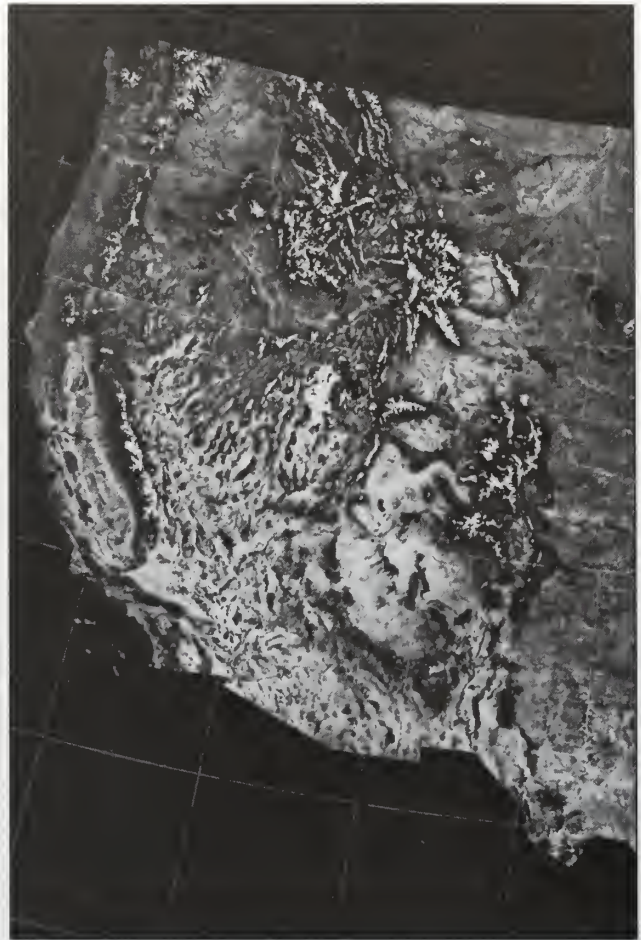


Figure 19. A NOAA AVHRR weather satellite image mosaic produced by USGS of the entire Western U.S. Besides being used for weather forecasting, the images can be used for monitoring seasonal greenup and global changes.

Other Satellite Based Sensors

Other potential-satellite based sensors collect data about the earth's surface, but have limited application for resource mapping activities. These sensor's include SEASAT, which measures sea surface elevation, and satellite measurement of the earth's gravity and magnetic fields. Space radar

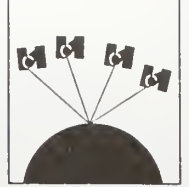
data has been collected during NASA's Space Shuttle experiments, but is not available on a regular basis. Space radar has identified archeology features not readily identifiable with other sensors; radar has also shown potential for mapping near surface ground water.

Russian Imaging Satellite Systems

Russia (Commonwealth of Independent States) has recently reached an agreement with the SPOT Corporation to distribute Sojuzkarta color photography and Almaz Radar imagery. The Sojuzkarta has had three camera sensors with archives beginning in 1970. This photo imagery has been reported to have more detail than SPOT or TM sensor data. Because this photography system uses camera film that has to be returned to earth for processing, the system cannot be as responsive to user demands for continuous coverage as the scanning systems used on SPOT and Landsat satellites. Nominal resolution is reported to be 5 meters with 80- x 100-km (50- x 60-mile) frame coverage.

The ALMAZ SAR satellite, the world's first commercial radar satellite, was launched in March 1991 with a follow-on scheduled in 1993. The SAR imagery is an all-weather, day or night, active sensor that illuminates the earth with microwaves that are reflected back to the satellite and recorded. SAR imagery is very sensitive to sudden terrain changes for geologic mapping, imaging sea ice, ocean surface wave patterns, oil slicks, soil moisture, and limited ocean floor topography. Both ALMAZ SAR and Sojuzkarta imagery are available from the SPOT Image Corporation.

Satellite Positioning Systems



Over the last 25 years, positional science has been adding space-based telemetry techniques to obtaining ground coordinates. At an American Congress on Surveying and Mapping (ACSM) Convention in St. Louis, MO, the term “Astrodetics” was used by Dr. Joseph Pelton, Director of Strategic Policy, Intelsat, to include measurements and mapping from space. These new passive and active space-based measurement

systems are changing the very nature of positional science to one that can give precise coordinates very quickly on any ground position. Satellite positioning systems have one thing in common—receiver hardware has to be taken to every field location to be mapped. There are currently three operational satellite positioning systems available for land management coordinate determination activities.

ARGOS Data Collection and Location System

System Description

The ARGOS Data Collection and Location System (DCLS) and earlier active satellite telemetry systems have been used the past 22 years to identify and locate big game animals and other natural resource phenomena. ARGOS DCLS is a cooperative project of the Centre National d’ Etudes Spatiales of France, the National Ocean and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). ARGOS DCLS uses transmitters operating at 401.650-MHz frequency on the ground and receiver instruments aboard two Tiros-N-series weather satellites. The system uses the ground station’s calculations of transmitted signals from a single satellite to estimate ground coordinates obtaining accuracies of 200-300 meters for known stationary control locations.

The use of ARGOS DCLS for biotelemetry evolved after 1980 with the production of small transmitters and long-lasting batteries. These units weigh approximately 2 kg when used in a collar for big game. Fancy et al., 1988, reviewed the ARGOS DCLS capabilities in satellite biotelemetry. They stated, “The mean positional error for the combined data set was 829 m (± 26 SE). Ninety

percent of the estimated locations were within 1,700 m of true location and the maximum error was 8.8 km.”

Main Uses

The ARGOS DCLS has been used to obtain both coordinates and data for a large diversity of subjects including polar bears, grizzly bears, gray wolves, mule deer, walrus, caribou, musk oxen, Dall sheep, elk, sharks, sea turtles, dolphins, whales, bald eagles, ocean buoys, drifting ice or nets, ships and yachts, etc. (Fancy, 1988).

Resource Mapping Potential

This system has the potential to obtain stationary positions within 235- to 320-meter RMS with moving objects at better than ± 800 meters as reported in Fancy et al., 1988. These seemingly low accuracies for biotelemetry are excellent when compared to the cost of ground-based location monitoring systems. Costs for startup in this operational technology are less than \$10,000, including a transmitter and reception and coordinate calculations service. Because the ARGOS DCLS is an active system, it can be used to transmit limited amounts of data to the satellite and then to the processing ground station.

TRANSIT Satellite Positioning System

System Description

The TRANSIT positioning satellite system was developed by John Hopkins University Applied Physics Laboratory for the U.S. Navy Navigation Satellite System. The first prototype was launched

in 1961, and became available for domestic use in 1967 (Wells, 1987). TRANSIT is a passive system requiring a ground receiver for the user, the TRANSIT satellite, and satellite tracking and control facilities. The TRANSIT system uses the Doppler shift measured at a known station and remeasured at an

unknown position. Surveyors refer to this sensor as the "Doppler" survey system. Satellite parameters are then applied to calculate ground coordinates of the unknown position. Six TRANSIT satellites are fully operational and transmit data on two carrier frequencies. BLM's TRANSIT operations required approximately 48 hours on station using a minimum of two and as many as five ground receivers in a differential mode with at least one receiver on known geodetic control. The satellite transmissions were recorded on a tape drive for later processing. All "Doppler" coordinates are derived through postprocessing in the office, making long costly revisits to the field necessary to correct errors detected in post-processing (Wells, 1987).

Main Uses

BLM's primary use for the TRANSIT positioning system is to obtain control coordinates for land-nets. Doppler control coordinates are obtained on township corners for processing in the Bureau's PLSS adjustment software described in the Terrestrial Positioning Systems section.

Coordinates can be calculated for all survey corners within a township. TRANSIT data can also be used for engineering survey control, photogrammetric aerotriangulation control, and precise locations for point or linear coordinates, such as long pipelines or powerlines. BLM has used Doppler to precisely locate coal drill holes and oil and gas wells. The accuracy of TRANSIT measurements is dependent on the number of satellite passes observed. The 48-hour observation periods obtain accuracies of approximately 1 meter. TRANSIT control coordinates were used in the calculation of the new NAD 83 and the worldwide WGS 84 datums.

Resource Mapping Potential

The TRANSIT system was the only cost-effective satellite positioning system for geodetic point positioning until the use of GPS. The satellites are scheduled to be in operation until 1994. The Air Force NAVSTAR GPS is planned as its replacement (Wells, 1987). As more and more NAVSTAR GPS satellites become operational, the need for TRANSIT is greatly reduced.

Global Positioning System

System Description

The U.S. Air Force is developing and deploying the NAVigation Satellite Time And Ranging (NAVSTAR) GPS as the replacement for the TRANSIT Doppler by 1994. The NAVSTAR system is operated similarly to the TRANSIT system with a final space segment configuration of 24 operating satellites. Twenty-three satellites from both Phase I and II are available for use. It is estimated that the Air Force will achieve initial full operational capability in the fall of 1993. The main control center used for time synchronization, orbit prediction, and satellite adjustment is located at the Consolidated Space Operations Center at Colorado Springs, CO. The users' segment receivers consist of a small antenna, GPS receiver unit, power supply, and portable data recorder/microcomputer in most natural resource applications. Extensive use of GPS receivers in the field has shown them to be more productive and accurate than the TRANSIT system. The current limited constellation of 23 satellites gives an observation window of almost a full day of the recommended 3-D coverage. When all 24 Phase II satellites are operational in 1994, a

24-hour window with both horizontal and vertical position capability will be available. The GPS will have two code signals available, one for U.S. military use and the other for civilian use.

GPS was designed by the DOD to provide worldwide, all weather, 24-hour-per-day instantaneous geographic positioning and time information. GPS is a satellite-based triangulation system using measurements of radiowave carrier frequencies and transmitted codes to determine relative distances and geographic coordinates (Figure 20). GPS was developed for the military, but domestic applications are expanding rapidly. DOD has implemented a Selective Availability (SA) security system that limits accuracy to non-DOD users with a single GPS receiver to no worse than 100 meters, 95 percent of the time. If SA is not in operation, ± 15 -meter accuracies can be obtained with a single GPS receiver. Civilian users have developed highly accurate application techniques using two GPS receivers, with one located on a survey monument of known coordinates, and using differential post-processing to refine the data. Field mapping accuracies better than a USGS topographic map (± 12.5 meters) can be obtained using this differential GPS

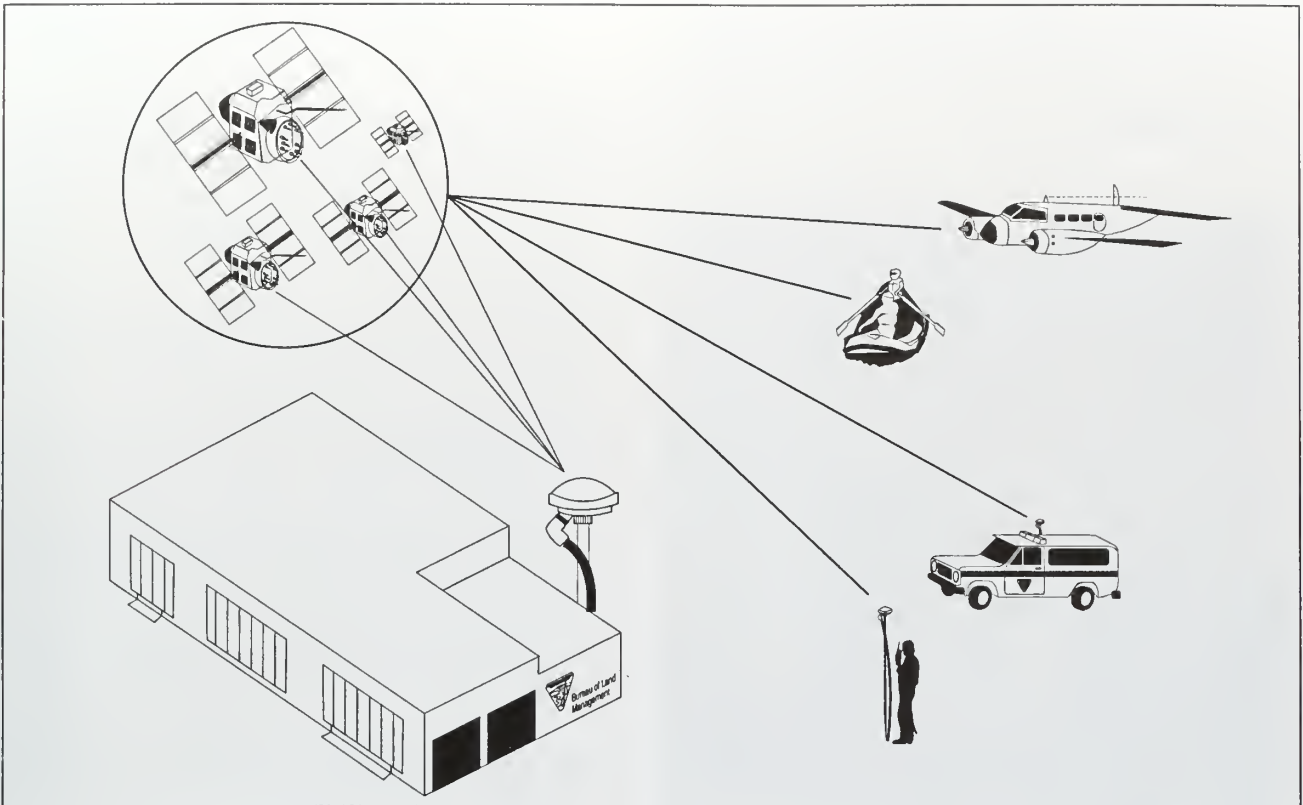


Figure 20. The GPS satellite constellation can be used for highly accurate positions of most BLM field activities. This illustration shows how a base station is used with field rover GPS receivers to map positions with differential corrected data. Ideally both the base station and field rover GPS receivers should view four or more satellites at the same time for the most accurate positions.

technique with inexpensive receivers. Relative line length survey accuracies to less than 10 centimeters can be obtained using more costly geodetic level GPS receivers and complex adjustment procedures. Differential GPS (DGPS) service is expanding and can provide real-time positions to ± 10 meters using radio communication between two receivers, with the stationary receiver base station transmitting differential adjustments to the roving GPS receiver.

GPS accuracies can range from 1 centimeter to more than 100 meters depending on the mode of operation, receiver quality and type, differential ground control, satellite constellation position, and final adjustment procedures. Textbooks have been written describing the numerous GPS application techniques. Resource GPS applications described in this guide are in three classes:

- **GPS navigation** uses a single code GPS receiver and can be performed with most receivers on the commercial market. A single GPS receiver must have three or more satellites visible above the horizon to derive a horizontal geographic coordinate. Four or

more satellites provide the best horizontal geo-positioning solution with altitude. Special low-cost (<\$600), handheld receivers are available for navigation functions. Caution must be used with single unit navigation applications due to the DOD implemented SA; accuracies can be degraded to 100 meters or more during periods of SA implementation (DOD states that SA will be on permanently) and poor satellite visibility. Even with SA on, accuracies from 35 to 100 meters can be obtained when four or more satellites are in good geometry. DOD has special GPS receivers that negate SA degradation to ± 15 meters in the single receiver mode, but they are only available to DOD-approved applications. Even with the SA limitations, GPS can provide the best geo-positions for mobile land and air navigation use. In order to improve GPS accuracies, scientists have devised procedures using two or more receivers to work around system limitations. These differential applications are described below. Currently, with

SA implemented, single GPS receiver accuracy is less than several other geo-positioning techniques when used for resource mapping.

- **GPS resource mapping** application techniques use two or more C/A-code GPS receivers with a base station receiver on a geodetic control with known geographic coordinates. The rover GPS receiver(s) collect satellite-transmitted data from the same set of satellites as the base station; differences in the two locations can be post-processed in a microcomputer. Differential adjustments can produce accuracies approaching 2 meters for stationary points and ± 5 meters for a roving receiver when all GPS variables are at their best. Most applications will fall within the 5- to 15-meter range when four or more satellites are visible. Five-meter accuracies are more than twice the National Map Accuracy Standard for a 7.5-minute, 1:24,000 scale topo map. A recent vendor announcement stated sub-meter results with a low-cost, handheld, 5-channel C/A and P code GPS receiver and 10 minutes of differential observation. Several vendors and the Coast Guard have proposed real-time DGPS service where existing communication systems or satellites will transmit the differential adjustments to the user's GPS receiver. Real-time DGPS navigation positional accuracies could approach ± 10 meters for air-, land-, or sea-based mobile platforms. Commercial DGPS services are currently available in the North Sea, the Gulf Coast, and several other locations, though many are experimental. DGPS would be very beneficial for aircraft flight-following systems to improve aviation navigation safety. If DGPS were available at ground level, then field natural resource navigation to a known or predicted coordinate would be easy; examples include locating a survey "brass cap" in the field or finding a previously inventoried archeological site.

Many Federal and State agencies have initiated permanent resource grade GPS community base stations. Base station receivers and computers can continuously collect GPS satellite data for later differential processing. The GPS data are normally

collected for 12 to 14 hours per day and stored on file server microcomputers or minicomputers. Data can be accessed through telephone modems or on computer networks to combine with the field collected GPS data, and then postprocessed into higher quality differential coordinates.

- **GPS geodetic surveying** using three or more P- and C/A-code, multiple-channel receivers, and multiple base stations on first order control monuments, can provide decimeter (10-cm) level accuracies with extensive postprocessing. Other geodetic level applications include: providing local or community GPS base station geographic coordinates for most differential applications, and testing and contributing to the refinement of the national geodetic control network. Survey-level applications include applying improved coordinates to cadastral surveys like BLM's developing Public Land Survey System/Geographic Coordinate Data Base (PLSS/GCDB). Also, ground control for photogrammetry and remote sensing projects can be provided. Several application techniques have produced centimeter-level linear measurement accuracies, ± 1 part per million (ppm), using a single GPS receiver in the kinematic mode. This mode needs a constant lock on four or more satellites. Geodetic receivers produce these high accuracies using the carrier phase P-code. DOD can encrypt the P code for Anti-Spoofing (AS) capability. This encryption will deny access to the more accurate and flexible carrier phase capability. GPS equipment vendors are developing procedures to negate encryption for differential survey applications.

Main Uses

The main purpose of GPS is to provide military air, sea, and ground units with a unified, high-precision, all-weather, instantaneous positioning capability. The number of resource management applications grows daily. BLM uses GPS for three major geo-positioning capabilities: navigation, resource mapping, and cadastral survey coordinate calculations as described in the TRANSIT Satellite Positioning System section.

Resource Mapping Potential

GPS is the only fully field-mobile, geo-positioning technology currently available for ground resource management activities (Figure 21). Releases of new systems have greatly reduced the cost and size of GPS, and thus increased its potential for land management applications. In the past year, several Federal natural resource agencies grew from a few geodetic/survey level receivers to hundreds of resource mapping and navigation GPS receivers (BLM, 1991). Several companies produce very small navigational "palm-held" systems and small field portable geodetic units. GPS is quickly supplementing the LORAN C navigation system, and may replace it in a few years. Operational development applications are performed in many BLM and USFS field offices as GPS becomes a viable geo-positioning and field mapping system. These applications support all resource management disciplines.

Accuracy of GPS keeps improving. Remondi, 1986, produced RMS results using kinematic surveying techniques of 0.6 cm in latitude, 1.0 cm in longitude, and 2.6 cm in height using GPS. He stated, "Not only does this permit real-time centimeter-level surveying in seconds, but also it would allow the user to navigate to within centimeters of a desired location in real time." Recent vendor claims indicate that systems providing centimeter-level accuracies in seconds are available, but users should be cautioned that these results require a highly trained and experienced geodesist and ideal conditions. GPS will not be fully operational until late

1993 or early 1994, but can be used on a daily basis with careful planning. The potential for natural resource mapping is evident, especially with all the current interest in a system that DOD has not declared operational.



Figure 21. A land surveyor measures the height of a Global Positioning System (GPS) antenna. The antenna is mounted on a tripod, which has been precisely set up over a survey point with a known location. Once the measurement is made, the receiver is turned on and data collection begins.

Other Satellite Positioning Systems

Emergency Location Transmitters (ELTs)—The ELT uses both aircraft and satellite receiving systems to identify aircraft and ship accident site locations. These small transmitters are required in all U.S. registered aircraft. The ELT system has five satellites, two U.S. and three Commonwealth of Independent States. They monitor the ELT emergency frequencies and locate the transmission to within approximately 1 kilometer. This system has limited resource use at this time due to their single emergency use.

GEOSTAR—Several commercial two-way (active) positioning systems have been in the planning stages. One, GEOSTAR, had undergone some

initial testing, but the corporation went out of business. GEOSTAR proposed the first continentwide communication and positional system. It was targeted at the transportation industry for identification, location monitoring, and communication to commercial vehicles. Electronic map displays in automobiles were a target application. GEOSTAR planned access through a subscription service. Accuracies were expected to be 10 to 50 meters. BLM used the communication component of GEOSTAR's first satellite to successfully test aircraft flight-following to assist in more accurate aircraft locations in emergencies. This very successful test used LORAN C-derived coordinates transmitted

from the aircraft to the GEOSTAR satellite, then to a ground station for display on a computer screen. Testing of GPS positions for flight-following was started when GEOSTAR went out of business (BLM, 1991). BLM plans to continue aircraft flight-following using other communications satellites.

European Space Agency NAVSAT— The European Space Agency has proposed NAVSAT, a commercial positioning system similar to GPS. This system design is proposed to have three classes of uses: navigation accuracy, high accuracy, and geodetic accuracy (Wells, 1987). When operational, this system could be used for global change monitoring activities.

GLONASS—Russia (Commonwealth of Independent States) has a 12-satellite GPS equivalent, GLONASS, designed as a one-way military

system. Russian civilians have access to their GPS (Wells, 1987) for point positioning. Several international aviation evaluations are underway testing joint GPS/GLONASS use for navigation, and prototype dual receivers have been tested in U.S. commercial aircraft. The use of a dual system should increase the reliability necessary for aircraft navigation. Commercial vendors are advertising dual GPS/GLONASS receiver capability.

Other Systems—Several companies in the telecommunications industry have proposed global positioning capabilities tied to a worldwide mobile telephone system that uses small satellites in low orbit. If this capability evolves into an operational system, geo-positioning will be available at mobile telephone costs. Implementation probability is high because of the design tie to mobile phones and support from the transportation and other industries.

Selecting a Geo-Positioning Technique

Each resource discipline should develop accuracy standards and identify both acceptable data inventory and mapping procedures to meet those data standards. The following general recommendations are offered to assist in the selection of a geo-positioning technique to meet specific resource needs:

1. If your resource data are identifiable on aerial photos, then delineating them on the photo and manually transferring the data to an overlay on an orthophotoquad would be the most effective technique to locate data. Resource data that transitions gradually on the ground, like vegetation or soils, should be pretyped on the aerial photo.
2. When documented legal descriptions and ground measurements are required, use cadastral ground surveys with ties to geodetic control or GPS positions.
3. If high-precision geographic coordinates are required for survey control, use geodetic survey quality GPS.
4. When better than 7.5-minute topo map accuracies are required, differential GPS or mapping photogrammetry should be used.
5. Photogrammetry is the most cost-effective tool for precise coordinates of digital terrain and engineering base maps.
6. Manually transferring data from aerial photos to topographic maps produces lower accuracies than using orthophotography or photogrammetric procedures.
7. If field site access is limited or not possible, remote sensing is indicated.
8. If detailed polygon data or random linework is mapped on overlays, then scan digitizing should be considered for cost-effective digital data entry. Use cartographic quality scanners to digitize resource data.
9. Point or straight line data on existing maps should be digitized with a digitizing tablet.
10. If the feature cannot be seen in an image, but is identifiable on the ground, then GPS is an excellent mapping tool. Aerial photos can be used as a map substitute, using other identifiable features to locate and map the feature that cannot be seen in the image.
11. Try to reduce long-term costs. If the initial project requires only cartographic accuracies, but future uses require precise coordinates of very high-value resource data, consider GPS and/or photogrammetry.
12. Costs are normally reduced and accuracies increased if coordinates are captured during the initial field inventory.
13. If large areas require resource data collection, then satellite remotely sensed data with digital image processing should be evaluated for cost-effective products.
14. If labor intensity and field operation costs are prohibitive, aerial photo interpretation or digital remote sensing should be used.
15. It is not cost effective to digitize data that contain errors and are not edge-matched. Quality control should be performed by the resource specialist when the data are collected. Digitizing error correction can double the cost of GIS data entry.

16. Consider all spatial analysis needs prior to selecting a geo-positioning technique. When a subcentimeter data set is combined with 20-meter data, both cost effectiveness and accuracy are lost.
17. Plan ahead to identify the source to be used for resource location coordinates when creating a GIS data base. Identify minimum project accuracy requirements. Projects have failed because the mapping accuracy requirement was not identified until late in the project. Select practical and realistic accuracies. For example, mapping third-order soil types with current GPS technology is not practical, but using aerial photography is cost effective.

The Future of Geo-Positioning Technologies

Predicting of the future of resource positional tools is very difficult, because of the rapid advances in computer technologies. While no major new technologies are expected in the next few years, increases in computer and electronic capabilities will greatly reduce the cost, increase the accuracy, and reduce the size of all geo-positional systems. Computer technology and digital data bases are causing a merger of space remote sensing, photogrammetry, and GIS into a set of spatial data processing tools.

- Increased commercial activity and a combination of commercial/international government competition in nonresource fields will give resource managers access to additional geo-positional capabilities.
 - The submeter, handheld, low cost (\pm \$500), active field positioning systems will be available in the next few years.
 - Geo-positioning services will be part of a worldwide mobile telephone system this century.
 - User location displayed on pen-based notebook computers with a digital map and tied to worldwide telecommunication systems are under development.
 - Geodetic GPS systems will produce centimeter accuracy in seconds for all users.
 - Superpositioning will be available on all stereoplotters and most GIS computer workstations, thereby providing the capability to combine digital map and image data.
 - Desktop digital photogrammetric devices will be available for less than \$25,000.
- Artificial intelligence and rule-based systems will assist in scanned resource data edits and monitoring global change in remote sensing analysis.
 - Combined real-time data and geo-positioning data collection in handheld field dataloggers are available as this guide goes to press. This application is only limited by the availability of real-time differential GPS service.
 - Handheld, electronic, navigational maps at VCR prices will be available this century.
 - New geo-positioning technologies will continue to identify errors and poor mapping techniques used in the past. Managers will have to appraise and set standards for basic resource mapping needs so as not to be driven by the next better technology.

The location of resource data is very important in the design of an integrated resource data base for use in spatial analysis systems. One of the described geo-positional tools will provide the correct economics and accuracies to meet most, if not all, resource manager's needs. Resource standard accuracy requirements should dictate the technology—not the other way around. The basic techniques reviewed in this paper have been evolving over the last 50 years, while the newer more exotic procedures are being operationally tested and used daily by technicians and scientists. Technologies are now available for all accuracy levels and needs of potential users. Users of this guide will innovate their own application-specific techniques, but should make all decisions based on predetermined resource data requirements and not the next better technology.

References

- Bureau of Land Management, 1973, *Manual of Survey Instructions*, U.S. Department of Interior, Bureau of Land Management, U.S. Govt. Printing Office, Washington, DC.
- , 1991, *Satellite Positioning Systems - A Report to the Director (an internal study)*, U.S. Department of Interior, Bureau of Land Management, Washington, DC.
- Brown, C., et al. 1988, *Using Side Scan Sonar Data in a Geographic Information System to Locate and Display Lake Trout Spawning Habitat in the Great Lakes*, unpublished paper presented at National MOSS User's Conference, New Orleans, LA.
- Craighead, F.C., Jr. and J.J. Craighead, 1969, *Radiotracking of Grizzly Bears in Yellowstone National Park, Wyoming*, Natl. Geog. Soc. Res. Rep., Washington, DC.
- , 1970, *Tuning in on the Grizzly*, Natl. Geog. Soc. Res. Rep., Washington, DC.
- Ehlers, M. and R. Welch, 1987, *Stereocorrelation of Landsat TM Images*, Photogrammetric Engineering and Remote Sensing, Vol. 53, No. 9:1231-1237.
- Evans, D.L., 1992, *Using GPS to Evaluate Aerial Video Missions*, GPS World, Vol. 3, No. 7, Eugene, OR.
- Fancy, S.G., et al., 1988, *Satellite Telemetry, A Tool for Wildlife Research and Management*, unpublished, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Fairbanks, AK.
- German, S., 1987, *Initial Attack Management System (IAMS)*, unpublished 1987 Information Package, Boise Interagency Fire Center (BIFC), Boise, ID.
- Goodenough, D.G., 1988, *Thematic Mapper and SPOT Integration with a Geographic Information System*, Photogrammetric Engineering and Remote Sensing, Vol. 54, No. 2:167-176.
- Hastings, D.A., and W.J. Emery, 1992, *The Advanced Very High Resolution Radiometer (AVHRR): A Brief Reference Guide*, Photogrammetric Engineering and Remote Sensing, Vol. 58, No. 8:1183-1188.
- Hatfield, M., 1978, *Location, Navigation and Survey-Adaptability of High Precision ESG Inertial Systems in the 1980's*, IEEE Plans 1978 Position Location and Navigation Symposium Record, San Diego, CA.
- Judd, S.L. and R.R. Knight, 1977, *Movements of Radio-Instrumented Grizzly Bears Within the Yellowstone Area, Bears-Their Biology and Management*, U.S. Government Printing Office, Washington, DC.
- Keating, J.B., 1988, *GIS Resource Data and GPS*, International Symposium on Advanced Technology in Natural Resource Management, Resource Technology 88, Ft. Collins, CO.
- , 1992, *BLM's TIN Modeling Assures Correct Coal Royalties*, GIS World, Vol. 5, No. 4:34-36, Ft. Collins, CO.
- Konecny, G., et al., 1987, *Evaluation of SPOT Imagery on Analytical Photogrammetric Instruments*, Photogrammetric Engineering and Remote Sensing, Vol. 53, No. 9:1223-1230.
- Maier, M., et al., 1983, *Locating Cloud-to-Ground Lightning with Wide Band Magnetic Direction Finders*, 5th Symposium on Meteorological Observations and Instrumentation, Toronto.
- Marvin, J.W., et al., 1987, *Derivation of Fast Algorithm to Account for Distortions Due to Terrain in Earth Viewing Satellite Sensor Images*, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-25, No. 2.
- Nakazawa, L. and L.A. Vanderlinden, 1986, *Survey Plot Meanderlines Determined by Photo Interpretation*, 1986 ASPRS-ACSM Fall Convention ASRRS Technical Papers, Falls Church, VA.

Pilmore, C.L., et al., 1981, *Computer-Assisted Photogrammetric Mapping for Geologic Studies-A Progress Report*, Photogrammetria, 36, p159-171, Elsevier Scientific Publishing Company, Amsterdam.

Remondi, B.W., 1986, *Performing Centimeter-Level Surveys in Seconds with GPS Carrier Phase: Initial Results*, Technical Papers Vol. 2, 1986 ACSM-ASPRS Annual Convention, 305-317, Falls Church, VA.

Rodriguez, V., et al., 1988, *Evaluation of the Stereoscopic Accuracy of the SPOT Satellite*, Photogrammetric Engineering and Remote Sensing, Vol. 54, No. 2:217-221.

Swann, R., et al., 1988, *The Potential for Automated Mapping from Geocoded Digital Imagery Data*, Photogrammetric Engineering and Remote Sensing, Vol. 54, No. 2:187-193.

U.S. Forest Service, 1985, *User's Guide to Photogrammetry & Other Advanced Technology for the Cadastral Engineering Program*, USDA, Washington, D.C.

U.S. Geological Survey, 1986, *Current and Proposed Earth Resources Observation Satellite System Reference Material for Federal Agency Workshop on "Basic Data Set Definitions,"* unpublished, Reston, VA.

Welch, R., et al., 1985, *Comparative Evaluation of the Geodetic Accuracy and Cartographic Potential of Landsat -4/-5 TM Image Data*, Technical Papers 1985 ACSM-ASPRS Fall Convention, Falls Church, VA.

Wells, D.E., et al., 1987, *Guide to GPS Positioning*, Canadian GPS Associates, Fredericton, N.B., Canada.

General References

Professional Journals

ACSM Bulletin, American Congress on Surveying and Mapping (ACSM), 5410 Grosvenor Lane, Bethesda, MD 20814-2122.

Cartography and Geographic Information Systems, Journal of American Congress on Surveying and Mapping (ACSM), 5410 Grosvenor Lane, Bethesda, MD 20814-2122.

Surveying and Mapping, Journal of American Congress on Surveying and Mapping (ACSM), 5410 Grosvenor Lane, Bethesda, MD 20814-2122.

Photogrammetric Engineering and Remote Sensing (PE&RS), American Society of Photogrammetry and Remote Sensing (ASPRS), 5410 Grosvenor Lane, Suite 210, Bethesda, MD 20814-2160.

Periodicals

Geo Info Systems, Aster Publishing, 1 Astor Place, P.O. Box 1965, Marion, OH, 43306-4152.

GIS World, 155 E. Boardwalk, Suite 250, Ft. Collins, CO, 80525.

GPS World, Aster Publishing, 1 Astor Place, P.O. Box 1965, Marion, OH, 43306-4152.

P.O.B. (Point of Beginning), P.O.B. Publishing Company, 5820 Lilley Road #5, Canton, MI 48187.

Professional Surveyor, Suite 105, 901 South Highland Street, Arlington, VA 22204.

Appendix A — Acronyms

| | |
|--------|--|
| ACSM | American Congress on Surveying and Mapping |
| ALDS | Automated Lightning Detection System |
| ALMRS | Automated Land and Mineral Record System |
| APL | Applied Physics Laboratory |
| APT | Automatic Picture Transmission |
| AS | Anti-Spoofing |
| ASPRS | American Society of Photogrammetry and Remote Sensing |
| AVHRR | Advanced Very High Resolution Radiometer |
| B&W | Black and White |
| BLM | Bureau of Land Management |
| CIR | Color Infrared |
| CIS | Commonwealth of Independent States |
| COGO | Coordinate Geometry |
| CSOC | Consolidated Space Operations Center |
| DBMS | Data Base Management Systems |
| DCLS | Data Collection and Location System |
| DCP | Data Collection Platform |
| DCW | Digital Chart of the World |
| DEM | Digital Elevation Model |
| DF | Direction Finders |
| DGPS | Differential Global Positioning System |
| DLG | Digital Line Graphic |
| DLG-E | Digital Line Graphic-Enhanced |
| DMA | Defense Mapping Agency |
| DOD | Department of Defense |
| DTED | Digital Terrain Elevation Data |
| EDC | Eros Data Center (USGS) |
| ELT | Emergency Location Transmitter |
| EMR | Electromagnetic Radiation |
| EOSAT | Earth Observation Satellite Company |
| EROS | Earth Resources Observation System |
| ERTS | Earth Resources Technology Satellite (now renamed Landsat) |
| ETM | Enhanced Thematic Mapper |
| GCDB | Geographic Coordinate Data Base |
| GCP | Ground Control Points |
| GGWL | Geographic Well Locator |
| GIS | Geographic Information System |
| GMM | GCDB Measurement Management |
| GOES | Geostationary Operational Environmental Satellite |
| GPS | Global Positioning System |
| HRPT | High Resolution Picture Transmission |
| IAMS | Initial Attack Management System |
| IR | Infrared |
| ISS | Inertial Survey System |
| LTP | Line Trace Plus |
| MSS | Multispectral Scanner |
| MTP | Master Title Plat |
| NHAP | National High Altitude Program |
| NAD 27 | North America Datum of 1927 |
| NAD 83 | North America Datum of 1983 |
| NAPP | National Aerial Photography Program |

| | |
|----------|--|
| NASA | National Aeronautics and Space Administration |
| NAVD 29 | North American Vertical Datum of 1929 |
| NAVD 88 | North American Vertical Datum of 1988 |
| NAVSTAR | NAVigation Satellite Time And Ranging |
| NGS | National Geodetic Survey |
| NIFC | National Interagency Fire Center |
| NMAS | National Map Accuracy Standards |
| NOAA | National Oceanic and Atmospheric Administration |
| ONC | Operational Navigation Chart |
| PAN | Panchromatic |
| PCCS | PLSS Coordinate Computational System |
| PLSS | Public Land Survey System |
| RBD | Resource Base Data |
| RMS | Root Mean Square |
| SA | Selective Availability |
| SAR | Synthetic Aperture Radar |
| SC | Service Center (BLM) |
| SCS | Soil Conservation Service |
| SLAR | Side Looking Airborne Radar |
| SPCS | State Plane Coordinate System |
| SPCS 83 | State Plane Coordinate System 1983 |
| SPOT PAN | SPOT Panchromatic |
| TIGER | Topologically Integrated Geographic Encoding and Referencing |
| TM | Thematic Mapper (Landsat) |
| USAF | U.S. Air Force |
| USDA | U.S. Department of Agricultural |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish & Wildlife Service |
| USGS | U.S. Geological Survey |
| UTM | Universal Transverse Mercator |
| VPF | Vector Product Format |
| WGS 84 | World Geodetic System 1984 |

Appendix B — Glossary of Geo-Positioning Terms*

*Sources: Multiple government technical dictionaries, glossaries and documents.

A

Absolute Coordinate System: Refers (in this document) to worldwide coordinate systems versus a relative coordinate system (local).

Accuracy: Closeness of an estimated (e.g., measured or computed) value to a standard or accepted value of a particular quantity.

Active System: A system having its own source of electromagnetic radiation (EMR) such as a radar or an ultraviolet blacklight.

Aerial: Relating to the air or atmosphere, being applicable in a descriptive sense to anything in space above the ground and within the atmosphere.

Aerial Film: A specially designed roll film supplied in many lengths and widths to fit aerial cameras. Emulsion types include panchromatic, infrared, color, and color infrared.

Aerial Photograph: A photograph of a part of the earth's surface taken by an aircraft-supported camera.

Aerial Photograph, Vertical: An aerial photograph made with the optical axis of the camera approximately perpendicular to the earth's surface and with the film as nearly horizontal as is practicable.

Airborne Scanner: A scanner designed for use on aircraft or spacecraft in which the forward motion of the vehicle provides coverage normal to the scan direction.

Algorithm: A computer-oriented, step-by-step procedure for solving a problem.

Altitude: (1) The distance of a location above a reference surface. The most usual surface is sea level. (2) Height of sensor platform above a specified datum, usually above mean sea level.

Analog: A form of data display in which values are shown in graphic form, such as curves. Also a form of computing in which values are represented by directly measurable quantities, such as voltages or resistances. Analog computing methods contrast with digital methods, in which values are treated numerically.

Ancillary Data: Subsidiary data used to define the area of interest, e.g., topographic, administrative, or geologic data. Ancillary data may be digitized and merged with the primary image data to facilitate analysis.

Antenna: The device that transmits and receives microwave and radio energy in SLAR systems.

Area Coverage: Complete photographic coverage of an area by conventional photography having parallel flight lines and stereographic overlap between exposures in the line of flight.

B

Band: A wavelength interval in the electromagnetic spectrum. For example, in Landsat, the bands designate specific wavelength intervals at which images are acquired.

Bench Mark: A relatively permanent, natural or artificial, material object bearing a marked point whose elevation above or below an adopted surface (datum) is known.

C

Central Meridian: The line of longitude at the center of a projection used as the basis for the construction of many map projections. An example would be the central meridian at the center of each UTM zone which is numbered 500,000 meters and used as the reference for east-west measurements within the zone.

Classification: The process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral reflectance characteristics.

Color: That property of an object that is dependent on the wavelength of the light it reflects or, in the case of a luminescent body, the wavelength of light that it emits. If this light is of a single wavelength, the color seen is a pure spectral color; if light of two or more wavelengths is emitted, the color will be mixed.

Color Infrared Film: Photographic film sensitive to energy in the visible and near-infrared wavelengths, generally from 0.4 to 0.9 micrometers; usually used with a minus-blue (yellow) filter, which results in an effective film sensitivity of 0.5 to 0.9 micrometers. Color infrared film is not sensitive in the thermal infrared region and therefore cannot be used as a heat-sensitive detector.

Contact Print: A photographic image produced by the exposure of a sensitized emulsion-coated paper in direct contact with a negative or positive film.

Continuous Strip Photography: Photography of a strip of terrain in which the image remains unbroken throughout its length along the line of flight.

Continuous Tone: An image which has not been screened and contains unbroken, gradient tones from black to white, and may be either in negative or positive form.

Contour: An imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface.

Control: (1) A control station. (2) The coordinates of a control station. (3) A collection of control stations. (4) The geometric data associated with a collection of control stations, such as coordinates, distances, angles, or directions between control stations. It is practically equivalent, in this sense, to basic control.

Control Point: A point to which coordinates have been assigned; these coordinates are then used in other (dependent) surveys.

Coordinate: One of a set of N numbers designating the location of a point in N -dimensional space. Coordinates are almost always associated with coordinate systems. A coordinate system provides an easy way for finding the point designated by the set of coordinates, or for assigning a set of coordinates to a point. The coordinates are said to be "in" the associated coordinate system. It is also common to speak of the associated point as being "in" that coordinate system.

Coordinate, Geodetic: One of a set of coordinates designating the location of a point with respect to the reference ellipsoid and with respect to the planes of the geodetic Equator and a selected geodetic meridian.

Coordinate, Geographic: (1) An inclusive term, used to designate either a geodetic or an astronomic coordinate. (2) The term may also designate one of a pair of coordinates that specifies the angular distances of a point from a meridian and from the Equator.

Coordinate System: A set of rules for specifying how coordinates are to be assigned to points.

Coordinate System, Cartesian: A coordinate system consisting of N straight lines (1-dimensional spaces) intersecting at one common point (the origin) and determining N distinct hyperplanes ($N-1$ -dimensional spaces).

Coordinate System, Geodetic: A coordinate system consisting of an ellipsoid, the equatorial plane of the ellipsoid, and a meridional plane through the polar axis.

Coordinate System, Grid: A coordinate system on a plane usually based on a map projection. The most common form is a rectangular Cartesian coordinate system. An example is the State Plane Coordinate System. Polar coordinate systems are also used, for example, in aviation and artillery firing. The advantage of a grid coordinate system is that plane coordinates may be substituted for geographic coordinates and the computations relating to them may be made by the simple methods of plane surveying.

Coordinate System, Local: A coordinate system that has its origin within the region being investigated and that is used principally for points within that region.

Coordinate System, State Plane: One of the plane rectangular coordinate systems for each State in the Union, established by the U.S. Coast and Geodetic Survey in 1933 for use in defining locations of geodetic stations terms of plane-rectangular Cartesian coordinates.

Corner (Land Surveying): A point on a land boundary at which two or more boundary lines meet.

D

Datum (Geodetic): A reference surface consisting of five quantities: the latitude and longitude of an initial point, the azimuth of a line from this point, and two constants necessary to define the reference spheroid. It forms the basis for the computation of horizontal control surveys in which the curvature of the earth is considered (leveling). A level surface to which elevations are referred, usually, but not always, mean sea level.

Data Collection Platform (DCP): The system on board Landsat that acquires information from ground-based instruments such as seismometers, flood gauges, and other measuring devices. These data are transmitted to the satellite and in turn are relayed to an earth receiving station.

Densification Survey: A control or cadastral survey that establishes increased accuracy or additional detail in an existing survey.

Digital Data: Data displayed, recorded, or stored in binary notation.

Digital Image: An image having numeric values representing gray tones. Each numeric value represents a different gray tone.

Digital Image Processing: Computer manipulation of the digital values for picture elements of an image.

Digitization: The process of converting spatial information, originally compiled on orthophotographic materials or base maps, into digital form for incorporation into a geographic information base. Also refers to the referencing of ground control points or lines to a remotely sensed image.

Digitizer: A device for scanning an image and converting it into numerical picture elements.

Displacement, Relief: The difference in the position of a point above or below the datum, with respect to the datum position of that point, owing to the perspective of an aerial photograph. Relief displacement is radial from the photo center. In truly vertical photography, relief displacement is radial from the principal point of the photograph.

Display: A graphic representation of output data from a device or system, for example, on a radar scope. The CRT is a widely used display device for output of "electronic" sensor data.

Distortion: Any shift in the position of an image on a photograph which alters the perspective characteristics of the photograph. Causes of image distortion include lens aberration, differential shrinkage of film or paper, and motion of the film or camera.

Doppler Shift: The difference between the frequency of radiation received at a point and the frequency of the radiation at its source, when observer and source are moving with respect to each other.

E

Electromagnetic Radiation (EMR): Energy propagated through a vacuum or material medium in the form of an advancing interaction between electrical and magnetic fields. Includes radio waves, heat waves, light waves, etc., depending upon frequency. The term radiation is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy or simple radiation.

Electromagnetic Spectrum: The ordered array of all electromagnetic radiation that propagates at the velocity of light and is characterized by wavelength and frequency. Wavelengths in the range of 0.3 to 15.0 micrometers are used most frequently in remote sensing.

Elevation: The distance of a point above a specified surface of constant potential; the distance is measured along the direction of gravity between the point and the surface.

Ellipsoid: A closed surface whose planar sections are either ellipses or circles.

Enhancement: The process of altering the appearance of an image so that the interpreter can extract more information. Enhancement may be done by digital or photographic methods.

F

False Color Image: A color image in which the dye color or ink is not the same as the scene color. Digital processing may produce false color images where the infrared wavelengths are represented by red, the red band as green, and the green as blue.

Film: The light-sensitive photographic emulsion and its transparent base.

Focal Length: The distance measured along the lens axis from the rear nodal point of the camera lens to the plane of best average definition over the entire field used in the aerial camera.

Format: The size and scale of an image.

G

Geodesy: (1) The science concerned with determining the size and shape of the Earth. (2) The science that locates positions on the Earth and determines the Earth's gravity field.

Geoid: A theoretical figure of the earth using a continuous surface that is perpendicular at every point to the direction of gravity. The geoid would coincide with the ocean surface if the latter were undisturbed and affected only by the earth's gravity field.

Geometric Correction: Spatial reorganization of a data set to match a predetermined set of spatial conditions.

Geocoding: Geographical referencing or coding of data.

Geometrical Transformations: Adjustments made in image data to change its geometric (spatial) character.

Global Positioning System (GPS): A navigational and positioning system, under development (1986) by the U.S. Department of Defense, by which the location of a position on or above the Earth can be determined by a special receiver at that point interpreting signals received simultaneously from several of a constellation of special satellites.

Globe: A spherical body.

Graticule: A network of lines on a map representing geographic parallels and meridians.

Grid: (1) A network composed of two families of lines such that a pair of lines, one from each family, intersects in no more than two points. (2) (Geodesy) A grid composed of two sets of uniformly spaced straight lines intersecting at right angles (derived from a square Cartesian coordinate system).

Grid Tick: A very short line (tick) drawn perpendicularly to the neat line of a map, to indicate a point on the neat line through which a line of a grid would pass if drawn. Grid ticks come in pairs, one on each of two opposite neat lines.

Geographic Information System (GIS): A data base management system used to store, retrieve, manipulate, analyze, and display spatial information.

Ground Control Point (GCP): A geographic feature of known location that is recognizable on images and can be used to determine geographic corrections.

Ground Data: Information concerning the actual state of ground conditions at the time of a remote sensing overflight.

Ground Receiving Station: A facility that records image data transmitted by satellites.

Ground Resolution Cell: The area on the terrain that is covered by the instantaneous field of view of a detector. Size of the ground resolution cell is determined by the altitude of the remote sensing system and the instantaneous field of view of the detector.

H

Hectare: Unit of land measure equal to 100 meters square. Equivalent to 2.471 acres.

I

Image: The representation of a scene as recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired by nonphotographic methods.

Imagery: Collectively, the representations of objects reproduced electronically or by optical means on film, electronic display devices, or other media.

Image Enhancement: Any one of a group of operations which improve the detectability of the targets of interest. These operations include, but are not limited to, contrast enhancement, edge enhancement, spatial filtering and noise suppression, and image sharpening.

Infrared Film: Photographic film sensitized to record near infrared wavelengths beyond the red end of the light spectrum. It is also sensitive to blue and ultraviolet light and must be used with a red filter to screen out these wavelengths.

Infrared Radiation (IR): Pertaining to or designating that portion of the electromagnetic spectrum lying between the red end of the visible spectrum (about .7 micrometers) and an indefinite upper boundary sometimes arbitrarily set at 1,000 micrometers, the lower limit of the microwave region.

Infrared Scanner: An instrument for obtaining thermal infrared imagery through line-scanning techniques.

Infrared Thermal Sensing: Line scanning techniques using infrared scanners with detectors. Usually, the imagery is obtained from selected portions of the 3 to 14 micron region of the spectrum.

K

Kilometer: Unit of length equal to 1,000 meters. Equals 0.6214 statute miles.

L

Land Cover: The biophysical materials covering the surface of the land, including soil, water, vegetation, and human cultural activities.

Landsat: A series of unmanned earth-orbiting NASA satellites which transmit multispectral images in the 0.45 to 12.5 micrometer region of the spectrum to earth receiving stations. (Formerly ERTS.)

Latitude: A linear or angular distance measured north or south of the equator on a sphere or spheroid.

Longitude: A linear or angular distance measured east or west from a reference meridian (usually Greenwich) on a sphere or spheroid.

Location: The numerical or other identification of a point (or object) sufficiently precise so the point can be situated. For example, the location of a point on a plane can be specified by a pair of numbers (plane coordinates) and the location of a point in space can be specified by a set of three numbers (space coordinates). However, location may also be specified in other terms than coordinates. A location may be specified as being at the intersection of two specific lines by identifying it with some prominent and known feature (e.g., "on top of Pike's Peak" or "at the junction of the Potomac and Anacostia Rivers").

Loran-C: A radio navigation system. The term Loran was originally an acronym for Lo(ng)-Ra(nge) N(avigation).

M

Map: A conventional representation, usually on a plane surface and at an established scale, of the physical features (natural, artificial, or both) of a part or the whole of the Earth's surface. Features are identified by means of signs and symbols, and geographical orientation is indicated.

Map, Engineering: A map that shows information essential for planning and estimating the cost of an engineering project or development. An engineering map is usually a large-scale map of a comparatively small area or of a route. It may be made entirely from the data gathered by an engineering survey or from information collected from various sources and assembled on a base map.

Map, Planimetric: A map which shows only the horizontal positions of the features represented.

Map, Topographic: A map showing the horizontal and vertical locations of natural and artificial features. It is distinguished from a planimetric map by the presence of quantitative symbols showing the relief.

Map, Thematic: A map that depicts particular features or concepts. In conventional use, this term excludes topographical maps.

Meridian: A north-south line from which differences of longitude (or departures) and azimuths are reckoned.

Meridian, Grid: A line of a map grid parallel to the line representing the central meridian.

Monument: A structure that marks the location of a corner or point determined by surveying.

Microwave Region: Commonly, that region of the electromagnetic spectrum in the wavelength range from 1 micrometer to beyond 1 meter.

Multispectral: Refers to remote sensing in two or more spectral bands, such as visible and near-infrared regions of the spectrum.

Multispectral Scanner: A nonphotographic imaging system which utilizes a rotating mirror and a fiber optic bundle sensor. The mirror sweeps from side to side and sequentially records brightness values (i.e., signal strengths) on magnetic tape for successive pixels, one swath at a time. The forward motion of the sensor platform carries the instrument to a position along the orbital path where an adjacent swath can be imaged.

N

National Map Accuracy Standards (NMAS): For horizontal accuracy maps at publication scales larger than 1:20,000, 90 percent of all well-defined features, with the exception of those unavoidably displaced by exaggerated symbolization, will be located within 1/103 inch (0.85 mm) of their geographic positions as referred to the map projection; for maps at publication scales of 1:20,000 or smaller, 1/50 inch (0.50 mm). For vertical accuracy, 90 percent of all contours and elevations interpolated from contours will be accurate within one-half of the basic contour interval. Discrepancies in the accuracy of contours and elevations beyond this tolerance may be decreased by assuming a horizontal displacement within 1/50 inch.

Navigation System, Doppler: In general, any navigation system which makes use of the measured shift in frequency of a signal of known frequency to determine the velocity of the receiving system relative to the signal source and, from these measurements, the location of the receiver.

Navigation System, Inertial: Any navigation system in which gyroscopes or accelerometers are used to provide a coordinate system which has a fixed orientation with respect to the distant galaxies.

Navigation System, Satellite: (1) A navigation system used for the navigation of satellites. (2) A navigation system having beacons or transponders placed on satellites rather than at fixed points on land.

Near Infrared: The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 (visible red) to around 2 or 3 micrometers (varying with the author). The longer wavelength end grades into the middle infrared. The term includes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only present during the daylight hours.

O

Orthographic Projection: A map plotting system whereby parallel lines project from points on the sphere to a plane tangent to the sphere at the map center.

Orthophotograph: A photograph derived from perspective photographs and equivalent to a photograph made by orthographic projection. In a perfect orthophotograph, there are no displacements of images because of tilt or relief.

Orthophotomap: A photomap prepared from an orthophotograph or a precisely controlled assembly of orthophotographs. It is generally published in standard map format.

Orthophoto Mosaic: An assembly of orthophotographs, usually precisely controlled, to form a uniform-scale photographic representation of a portion of the earth's surface.

Orthophotoscope: An instrument for converting conventional perspective photographs into orthophotographs by differential rectification.

Orthophotoquad: An orthophotograph or mosaic of orthophotographs at the size of a standard quadrangle (a scale of 1:24,000) with little or no cartographic work added to it.

Overlap: The amount by which one photograph duplicates the area covered by another photograph, usually expressed as a percentage. Overlap may be end or forward (along the flight path) or side (taken during two or more parallel flights); both end and side overlap are customary when more than one line is flown.

Overlay: (1) A transparent medium on which flight lines and/or area to be photographed are plotted to be superimposed on a map, thus avoiding defacing the map. (2) Digitally merging two digital data sets.

P

Panchromatic: Photographic emulsion sensitive to all colors of light.

Panel: A target used for ground control or point identification during aerial photography.

Paneling: Marking points on the ground with material of suitable contrast, size, and shape to provide images which can be positively identified on aerial photographs.

Parallax: The apparent displacement of position of a body with respect to a reference point or system of coordinates, caused by moving the point of observation.

Parallel, Geographic: A line on the Earth, or a representation thereof, which represents the same latitude at every point. Also called a parallel of latitude or, when no misunderstanding is possible, a parallel.

Passive System: A sensing system that detects or measures radiation emitted by the target.

Photogrammetry: The art and science of obtaining reliable measurements by means of photography.

Photogrammetry, Aerial: Photogrammetry in which photographs or other images of the Earth taken from aircraft or satellites are used.

Photogrammetry, Analytical: Photogrammetry in which the shape and size of an object are determined mathematically from measurements directly on the images, rather than mechanically from measurements on the stereoscopic model.

Photograph: A representation of objects formed by the action of light on silver halide grains within an emulsion.

Photography: The process of producing images on sensitized material by exposure to light.

Photomap: An assemblage of aerial photographs that, wholly or partially, substitutes for or supplements a map. The photographs may or may not be rectified or restituted.

Photomosaic: An assemblage of photographs, each of which shows part of a region, put together in such a way that each point in the region appears once and only once in the assemblage, and scale variation is minimized.

Phototriangulation: (1) The determination of horizontal or vertical coordinates from measurements of angle, distance, or coordinates of points on overlapping photographs. (2) The method by which horizontal or vertical control is determined from measurements of angle, direction, or coordinates of points on overlapping photographs.

Pixel: An element of surface resulting from subdividing an image into the smallest identically shaped figures that give information about the location, intensity, and perhaps color of the source, but which at no smaller subdivision will provide more information. The concept of "pixel" (diminutive of "picture element") is valid only for images made up of discrete patches. It is not valid for continuous images. The term is sometimes assumed to be the equivalent of resolution expressed in terms of area. However, it is not exactly equivalent, because resolution can be defined for pictures which do not contain pixels. The size of a pixel is set principally by the size of the smallest individual radiation-sensitive element in the instrument creating the image. For example, in the human eye, the pixel is the region occupied on the retina by a cone.

Platform (Sensor): Vehicle on which a remote sensing device is mounted and carried aloft; an aircraft platform, space platform.

Position: (1) A numerical or other description of the location and orientation (attitude) of an object. (2) A numerical or other description of the location of a point or object. In particular, in geodesy and navigation, (a) data which give the location of a point in a specific coordinate system, (b) the place occupied by a point on the Earth, (c) the coordinates giving the location of a point on the geoid or ellipsoid.

Position, Geographic: The location of a point on the surface of the Earth, expressed in terms of either geodetic or astronomic latitude and longitude. Geo-position is a contraction of this term.

Positioning System: Generally, a system (equipment, procedures, and personnel) used for locating a vehicle or, less frequently, an instrument. A navigation system can also be used for positioning, but a system designed specifically for positioning generally gives more accurate locations.

Positioning System, Doppler: A positioning system consisting of a radio receiver at the point whose coordinates are to be determined, one or more beacons in orbit about the Earth, and a computing system for determining the orbits of the beacons.

Positioning System, Inertial: A positioning system consisting of a computer and an assemblage of three accelerometers and two or three gyroscopes.

Positioning System, Radio: A positioning system in which the travel time or phase shift of radio waves is measured.

Positioning System, Satellite: A positioning system consisting of a radio receiver, or a receiver and transmitter, at the point whose location is to be determined, one or more beacons or transponders in orbit about the Earth, and a computing system for determining and predicting the orbits.

Precision: The degree of refinement in the performance of an operation, or the degree of perfection in the instruments and methods used when making the measurements. Precision relates to the quality of the operation by which a result is obtained, and is distinguished from accuracy, which relates to the quality of the result.

Preprocessing: Application of digital image processing techniques to the raw remote sensor data prior to visual or further machine-assisted image analysis.

Projection: A systematic drawing of lines on a plane surface to represent the parallels of latitude and meridians of longitude of the earth or a section of the earth.

Protraction: In land and cadastral surveying, the subdivision of land by drawing or extending lines on maps or plats of the region being subdivided. The lines are drawn before surveying and monumenting the subdivisions and are therefore indicated by dashed, straight lines.

R

Radar, Side-Looking: A form of radar, mounted on aircraft, in which the beam is pointed, either by scanning or by shaping, in a direction perpendicular to the longitudinal axis of the aircraft so that the returned signals come from a long, narrow strip of ground approximately perpendicular to the airplane's line of flight. The ground is mapped as a set of adjacent, overlapping strips.

Radar, Synthetic-Aperture: A radar containing a moving or scanning antenna; the signals received are combined to produce a signal equivalent to that which would have been received by a larger, stationary antenna.

Radiation: Process by which electromagnetic energy is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space.

Raster Image: An image represented by a series of lines and samples.

Real-Time: To make images or data available for inspection simultaneously with their acquisition.

Rectification: (1) The process by which the geometry of an image area is made planimetric. (2) The process of converting a tilted or oblique photograph to the plane of the vertical by projecting it onto a horizontal reference plane, with the angular relationship determined by the use of control points recognizable on the photograph and an accurate map.

Reflectance: A measure of the ability of a surface to reflect energy in the various regions of the electromagnetic spectrum. Reflectance is affected not only by the nature of the surface itself, but also by the angle of incidence and the viewing angle.

Registration: The process of superimposing two or more images or photographs so that equivalent geographic points coincide. Registration may be done digitally or photographically.

Remote Sensing: The collection of information about an object without being in physical contact with the object.

Resolution: A measure of the finest detail distinguishable in an image. Resolution usually varies from point to point of an image, so an average value (area-weighted average resolution) is often used as the resolution of the entire image.

Resolution, Ground: The size, in length or area, of the smallest pattern or region on the ground which can be distinguished on an image.

Root Mean Square (RMS): The square root of the average value of the sum of the squares of the differences between the values in a set and the corresponding values that have been accepted as correct or standard used to measure map accuracy.

S

Scanner: An optical-mechanical imaging system in which a rotating or oscillating mirror sweeps the instantaneous field of view of the detector across the terrain.

Scale (Noun): The ratio of two numbers a and b, where b is the length of a characteristic dimension of some object and a is the length of the corresponding dimension in a representation (model or map) of that object.

Scene: The area on the ground that is covered by an image or photograph.

Sensor: Any device that gathers energy (EMR or other), converts it into a signal, and presents it in a form suitable for obtaining information about the environment.

Signature: A characteristic, or combination of characteristics, by which a material or object may be identified on an image or photograph.

Sonar: An apparatus that detects the presence of, or determines the distance or direction of, an object underwater by receiving and interpreting sound from the object.

Spatial: Refers to the location of, proximity to, or orientation of objects with respect to one another in N-dimensional space. Generally refers to phenomenon that can be mapped in 2 or 3 dimensions on or near the earth's surface.

Spatial Resolution: The ability of an entire remote sensor system, including lens, antennas, display, exposure, processing, and other factors, to render a sharply defined image. Also, a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor.

Spectral Band: An interval in the electromagnetic spectrum defined by two wavelengths or frequencies.

Spectral Reflectance: The reflectance of electromagnetic energy at specified wavelength intervals.

Spectral Resolution: The dimension and number of specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive.

Spheroid: Any surface differing only slightly from a sphere. By extension, a surface close to the geoid or approximating the geoid.

Stereoscopic Coverage: Aerial photography taken with sufficient overlap to permit complete stereoscopic observation. Sixty percent forward overlap between frames is usually recommended for adequate stereoscopic coverage.

Stereoscopic Pair: Two photographs of the same area taken from different camera stations so as to afford stereoscopic study of the overlap area. Also called stereo pair.

Stereoscope: An instrument that uses a stereoscopic pair of images to produce a visual effect of depth or solidity, numerical data, or topographic maps showing depth (height).

Superpositioning: The capability of overlaying, normally an aerial image and a line map, for the purpose of data collection or data maintenance.

Survey, Control: A survey that provides coordinates (horizontal or vertical) of points to which supplementary surveys are adjusted.

Survey, First-Order: A geodetic survey of the highest prescribed order of precision and accuracy.

Survey, Geodetic: A survey that takes into account the size and shape of the Earth (as distinguished from a plane survey, in which the surface of the Earth is considered a plane).

Surveying, Plane: Surveying done under the assumption that the surface of the Earth is flat.

Synoptic View: The ability to see or measure large areas at the same time and under the same conditions (i.e., the overall view of a large portion of the earth's surface which can be obtained from satellite altitudes).

System: Structured organization of people, theory, methods, and equipment to carry out an assigned set of tasks.

T

Thermal Infrared: Electromagnetic radiation emitted by any substance as a consequence of the thermal excitation of its molecules. Thermal radiation ranges in wavelength from the longest infrared radiation to the shortest ultraviolet radiation.

Theodolite: A precision surveying instrument for measuring horizontal and vertical angles. The graduated circles are usually read by means of optical microscopes and are more precisely graduated than are the circles on a transit. (See Transit.)

Total Station: A fully automated surveying device that measures both distances and horizontal and vertical angles, recording them on a magnetic device.

Transit: A repeating surveying instrument for measuring horizontal and vertical angles. The graduated circles are usually not graduated as precisely as are those on a theodolite.

V

Vertical Photograph: An aerial photograph taken with the axis of the camera being maintained as closely as possible to a truly vertical position, with the resultant photograph lying approximately in a horizontal plane.

W

Wavelength: Wavelength equals velocity/frequency. In general, the mean distance between maxima (or minima) of a roughly periodic pattern. Specifically, the least distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and infrared wavelengths are measured in nanometers, micrometers, and angstroms.

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Geo-Positioning Selection Guide

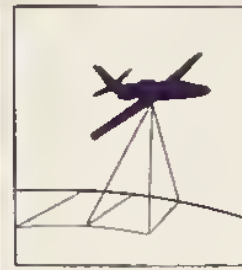
a reference to select systems and techniques for obtaining and mapping natural resources or cultural data

| Accuracy Levels | Geo-Positioning Tools | Horizontal Accuracy Estimate | Vertical Accuracy Estimate | Cost Class | Spatial Data Type | | | | Direct Digital | Comments | |
|--|---|------------------------------|----------------------------|------------|-------------------|-------|------|------|----------------|-------------------|----------------------|
| | | | | | Cell Size | Point | Line | Area | | | |
| Site Specific Applications Scales Larger Than 1:12,000 Applications for valuable mineral or high visibility locations or surveying and engineering requiring the highest precision. | Survey/Geodetic GPS (Differential) | <10cm | <25cm | 1 | | X | | | X | Field, developing | |
| | Engineering Photogrammetry | ±10cm | ±25cm | 2 | | X | X | X | X | Stereoplotter | |
| | Ground Survey Ties to Geodetic Control | ±10cm | ±20cm | 1 | | X | | | | Field | |
| Resource Applications Scales 1:12,000 to 1:25,000 Applications for medium to large areas needing more intensive accuracies and precision. Resource Base Data (RBD) should be mapped with these tools. Scales 1:24,000 to 1:62,500 Medium scale applications for large areas requiring less intensive accuracies and precision including most resource and planning uses. Navigation point positioning and less precise location of resources can be performed with a single GPS unit. | Resource Mapping GPS (Differential) | 5-15m | ±25m | 3 | | X | X | X | X | Field, developing | |
| | Mapping Photogrammetry | 5-10m | ±1-5m | 3 | | X | X | X | X | Stereoplotter | |
| | Digital Orthophotos (1:12,000 - 1:25,000) | 5-20m | n/a | 3 | 2-5m | | | | X | X | Developing |
| | Orthophotoquad (1:12,000 - 1:25,000) | 5-20m | n/a | 4 | | | | | X | | Under construction |
| | Stereo Photo Transfer to a Topo Map | 12-25m | n/a | 4 | | X | X | X | | | Simple stereoplotter |
| | Optical Photo Transfer to a Topo Map | 15-50m | n/a | 5 | | X | X | X | | | Optical equipment |
| | Aerial Photo to Topo Map | 25-75m | n/a | 5 | | X | X | X | | | Field, manual |
| | Aerial Photo to Orthophotoquad | 15-50m | n/a | 5 | | X | X | X | | | Field, manual |
| | Field Plotting to a Topo Map | 25-100m | n/a | 5 | | X | X | X | | | Field, manual |
| | SPOT Satellite Panchromatic | 10-25m | 10-25m | 4 | 10m | | | | X | X | Terrain corrected |
| | Calculated Tie to PLSS GCDB | 10-100m | n/a | 4 | | X | | | | | Under construction |
| | Digital Line Graphic (DLG) 7.5' | 12-50m | n/a | 5 | | X | X | | | X | Under construction |
| | Digital Elevation Model (DEM) 7.5' | ±15m | 7-15m | 5 | 30m | | | | | X | Vertical only |
| Navigation GPS (Single GPS Unit) | 35-100m | ±100m | 4 | | X | | | | X | ±15m with SA off | |
| Regional Applications Scales Smaller Than 1:62,500 Smaller scale applications for regional areas needing less intensive or costly locations including projects covering entire districts, counties, or states. Lowest cost per ground measurement unit of coverage. Applications include unique monitoring, navigation, and less precise location of resources. | SPOT Multispectral Scanner | 20-50m | n/a | 4 | 20m | | | X | X | Terrain corrected | |
| | Landsat Thematic Mapper (TM) | 30-70m | n/a | 4 | 30m | | | X | X | Terrain corrected | |
| | Landsat Multispectral Scanner (MSS) | 70-150m | n/a | 5 | 80m | | | X | X | Terrain corrected | |
| | LORAN C | ±250m | n/a | 3 | | X | | | | Field | |
| | Digital Line Graphics (DLG) - 1:100,000 | ±50m | 10-25m | 5 | | X | X | | | X | Limited contours |
| | TIGER Files - U.S. Census Data | ±100m | n/a | 5 | | X | X | X | | X | Mixed data source |
| | Aerial Video With GPS | 35-100m | n/a | 3 | varies | | | | X | | Field, distorted |
| | DEM (30'x60' - 1:100,000) | ±50m | 5-25m | 5 | 2 arc sec. | | | | | X | Under construction |
| | DEM (1°x2° - 1:250,000) | ±100m | ±75m | 5 | 3 arc sec. | | | | | X | Vertical only |
| | ARGOS Satellite Transceiver | ±500m | n/a | 3 | | X | | | | X | Wildlife tracking |
| AVHRR Weather Satellite | ±1000m | n/a | 5 | 1km | | | | | X | Daily coverage | |
| Digital Chart of the World - 1:1,000,000 | ±2000m | ±650m | 5 | | X | X | X | | X | Very small scale | |

How To Use This Selection Guide

The purpose of this guide is to assist in selecting the best, most economical mapping tools or techniques for locating natural or cultural features and their geographic coordinates. The guide is not all inclusive; only major technologies used in natural resource land management activities are covered. The tools and techniques are compared on the basis of application, accuracy, cost, and other characteristics. Applications are divided into three major groups based on scale, size of area, and amount of detail needed. Accuracies are estimated based on BLM's experience and reasonable use of each technology, and are given in metric measurements for easy comparison. Costs are divided into five relative classes with class 1 being the most costly for mapping per hectare. Each technology is color coded for cross-referencing with a description of its associated discipline at the bottom of the guide.

Aerial Photography, Photogrammetry, & Orthophotography



Aerial photos, because of their vertical perspective and stereo images, can assist in identifying and mapping cultural and natural features. However, while aerial photos provide easy reference to ground locations in the field, they contain distortions, and therefore, any data collected must be transferred to maps or orthophotos, or used in a photogrammetric stereoplotter to obtain geographic coordinates. Aerial photos are normally used for site-specific and medium-scale resource applications.

Photogrammetry systems require aerial photography or digital images, ground control measurements, and optical or digital equipment to collect information for 2D or 3D maps and digital data bases. Accuracy is dependent upon scale and resolution of the aerial photography and ground control. Photogrammetry is best used in mapping larger areas at great detail, such as in large-scale engineering design maps with 2-foot or less elevation contours, and is the primary tool used to produce the 7.5-minute topographic map series of the United States. Photogrammetry is evolving from the use of large, expensive optical stereoplotters to digital analysis of scanned aerial images using computer workstations. All data from photogrammetry can be directly collected in digital format. Orthophotography and digital elevation models (DEMs) are produced using photogrammetry.

Orthophotographs, orthophotoquads, and orthophotomaps are aerial photos with distortions and displacements removed using special optical or digital equipment and software with ground control measurements and elevation data. Orthophotos have most of the visual benefits of aerial photos, plus the positional accuracy of a map. They are produced to a base datum and referenced to geographic coordinates. Field data can be visually transferred to orthophotos and then digitized into a Geographic Information System (GIS). Orthophotos can be produced as large-scale project base maps for engineering and landscape design, and as 7.5-minute, 1:24,000-scale companion products to USGS topographic maps. In addition, satellite images from SPOT or Landsat can be processed into hard-copy or digital orthophotos. The newest orthophotos are produced as digital images for computer use. Once an orthophoto is produced, it can be easily updated using new aerial photography.

Aerial Video with GPS - Video systems can be mounted in aircraft and flown for near real time imaging and interpretation, but they have limited geo-positioning capability due to the inability to remove distortions from the analog video image. Video cannot be used for precise mapping purposes, but differential global positioning can provide geographic coordinates to enhance the video frame location. Information can be extracted from a video frame and superimposed onto orthophotos for increased positional accuracy for change monitoring, pest inventories, etc.

Satellite Positioning Systems



Satellite/global positioning technologies have evolved over the last 25 years from several land and satellite based navigation systems into the current Global Positioning System (GPS). GPS is a satellite-based triangulation system using measurements of radio wave carrier frequencies and transmitted codes to determine relative distances and geographic coordinates. GPS was developed for the military, but domestic applications are expanding rapidly. The Department of Defense (DOD) has implemented a security system called Selective Availability (SA) that limits accuracy to non-DOD users with a single GPS receiver to no worse than 100 meters 95 percent of the time. If SA is not in operation, ± 15 meter accuracies can be obtained with a single GPS receiver. Civilian users have developed highly accurate application techniques using two GPS receivers with one located on a survey monument of known coordinates. Using inexpensive GPS receivers, this differential GPS technique can obtain field mapping accuracies equal to a USGS topographic map (± 12.5 meters). More costly geodetic level GPS receivers and complex adjustment procedures can obtain relative line lengths to less than 10 centimeters. Differential GPS (DGPS) service is expanding and can provide real-time positions to ± 10 meters using radio links between two receivers. GPS will not be fully operational until 1994, but can be used on a daily basis with careful planning. GPS is the only field mobile geo-positioning technology currently available for ground resource management activities.

ARGOS is an active radio wave system requiring a transmitter at the monitored location. ARGOS uses one moving satellite to receive continuous signals from a ground transmitter with geographic coordinates post-calculated at a ground base station. Small transmitters attached to animals are used to track wildlife in studies worldwide.

Terrestrial Positioning Systems

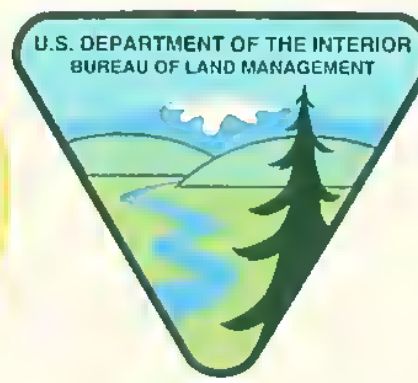


Traditional ground survey techniques have been used to establish the national datum frame of reference for natural resource mapping science and geo-positioning activities for the entire United States. The National Geodetic Survey has placed control monuments throughout the country which are used to determine geographic coordinates through survey ties to unknown locations. Most of the coordinates are based on the North

American Datum of 1927 (NAD 27), but can be adjusted to the more precise NAD 83. This type of geo-positioning can be very accurate, but is labor intensive.

Calculated Ties to PLSS/GCDB - Calculations can be made from known coordinates to project new coordinates if distance and bearing are known between the two locations. The developing BLM Public Land Survey System/Geographic Coordinate Data Base (PLSS/GCDB) can be used to calculate coordinates of a feature from a tied survey or map compilation. Positional accuracies can range from 5 meters with recent surveys and good geodetic control to more than 500 meters with older surveys and limited control.

LORAN C is a ground based radio-navigation system used for aviation and sea navigation for the entire United States. Accuracy is limited due to system design and terrain masking of the signal, especially at ground level. LORAN C can be used for general navigation to a field site or to obtain quick coordinates of ground activity from an aircraft.



U.S. Department of the Interior
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Cartographic Reference Systems



One of the most common techniques for determining geographic coordinates is to use existing maps or orthophotos for field compilation and then digitize the data into a GIS using a digital tablet or scan digitizing. Standard national map series, like the USGS 1:24,000-scale topographic quadrangles, or specially produced large-scale project base maps, can be used. Locating oneself in the field with a topo map is difficult because of limited detail, and errors can exceed 500 meters. It is more accurate to use an aerial photo, then transfer the location to the map.

Existing Digital Sources - Many geographic coordinate locations can be derived from existing digital maps or images, including:

- products produced to the National Map Accuracy Standards (NMAS), such as the USGS Digital Line Graphics (DLG) 1:100,000, 30 X 60-minute and 1:24,000, 7.5-minute formats
- U.S. Census TIGER files
- Digital Elevation Models
- Digital Chart of the World (DCW)

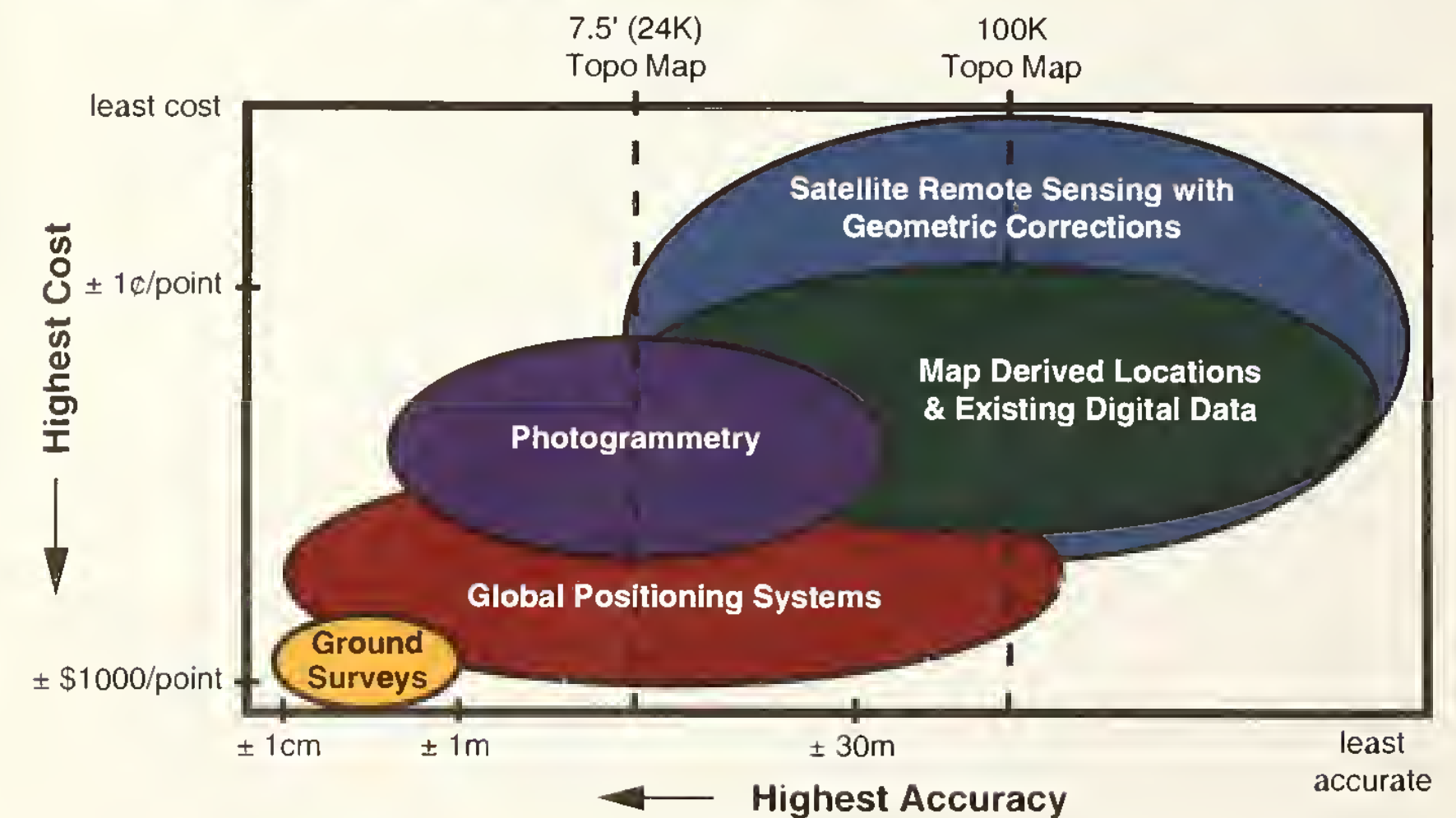
Many State and Federal agencies have digital project data bases with geographic coordinates, but the datum, coordinate system, and map projection must be known and the accuracy and resolution checked prior to their use.

Satellite Remote Sensing Systems



Satellite imagery has the lowest cost per hectare for resource mapping and can be used for large-area resource analysis and regional applications. Since the imagery is digital, it can be transformed into an image map (orthophoto) and, when rectified, used to derive geographic positions. Automated interpretation and enhancements can be performed using digital classification and analysis software on computer workstations. Satellite imagery is becoming more available and useful at the field level due to increased microcomputer capability and greater resolution of satellite sensors.

Comparison of Relative Cost vs. Accuracy



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